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Vol. 213 MARCH, 1932 No. 3

THE LOCOMOTIVE ON THE RAILROADS' BATTLEFIELD.*

BY

WILLIAM C. DICKERMAN, M.E.

President, American Locomotive Company.

To speak tonight before The Franklin Institute of Pennsylvania is a great pleasure. Yours is a body whose continuing and active existence has been a distinguished factor in the promotion of the Mechanic Arts in America. For more than a Century your contact with the progress of transportation has been intimate. During this time you have made many and significant contributions to the advance in railway equipment design. The Institute's recognition, through medal awards and otherwise, has long been a powerful stimulus to the inventor, not only in the United States, but abroad. You have today a special medal award reserved for recognition of achievement in the field of railroad transportation.

By all these tokens, it may be assumed that you are interested in the railroad locomotive! Therefore, it was a great delight to me to accept the invitation to discuss with you tonight: "The Locomotive on the Railroads' Battlefield."

The Locomotive on the Railroads' Battlefield! Immediately you may ask, *what* battlefield and *what* battle? My answer is: the battlefield is that of persistent struggle for railroad progress during the decade of 1920 to 1929, a battlefield spread out over forty-eight States. The battle: that of

* Presented at a meeting held Thursday, November 12, 1931.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

the railroads for continuingly progressive economies and efficiencies, for continuingly improved safety, and for progressively bettered service to the public. The battle is that against waste, against inefficiency, and against a constant menace of keener competition by other transportation agencies.

Besides these physical opponents of the railroads, there have been present throughout the ten years the elements of political antagonism, of aggressive taxation, and in some instances, of absence of complete public understanding of the railroads' problems. Perhaps too there has been lack of full appreciation by the public of the part which the railroads have played in making America what it is.

It is my purpose tonight briefly to analyze with you the fundamental characteristics—whether physical, economic or political—which largely have governed the progress of American railroading during this past decade. Moreover, I purpose to attempt to give you an insight into the measure of contribution which the steam locomotive has made during a decade which constitutes a record of operating achievement—in other words, an insight into the locomotive's part on this field of battle.

Those of you who may be familiar with something of the history of American railroading sixty years ago, will recognize an interesting coincidence in the fact that the ten years following the Civil War and the ten years following the World War, were each a period of railroad achievement but in different directions. The ten years from 1866 to the Centennial Exhibition in 1876 were notable as including the greatest relative expansion in railroad mileage ever experienced in this country. Railroad routes were rapidly extended virtually throughout the United States, and it was during this decade that the first transcontinental line was completed in 1869. History recognizes that the financial strain of this railway program was closely related to the causes which precipitated the panic and depression of 1873. By interesting contrast, the ten years following the World War, which is the decade we are examining, marks unprecedented progress in American railroading—along lines we will discuss together. Again by contrast, little charge is heard that the depression of 1930 was in any way

brought about by failure of the railroads to uphold their part in American commerce. Furthermore, I believe it a fair statement that the progressive economies of railroad operation during the decade just closed, in no small measure have alleviated the conditions through which the country has been passing. One of my reasons for making the statement lies in the fact that reduced inventories and modern merchandising and buying methods have largely been made possible by the increased efficiency of railroad service developed during these years which we will discuss together. In 1921, many of you will recall that industry was still further depressed by the existence of an inventory situation which happily does not exist today. So much for the preliminary introduction of our subject!

I propose to take as my text tonight a series of *sixteen graphical charts* that have been prepared especially for the purpose. My general sources for the data presented are the most authoritative and impartial obtainable; namely, the records of the American Railway Association, the Bureau of Railway Economics, and the Interstate Commerce Commission. To each of these are my appreciative thanks extended.

Statistics *per se* have long been recognized as a potent and delightful antidote for insomnia. Statistics, however, when presented in graphical form and with due regard to the humanities, lose much of soporific characteristic. These humanized charts then, will themselves largely tell my story.

While you are looking at them, keep in the back of your minds that the transportation situation in the United States is one that cannot yet be said finally to be crystallized. There still are elements of transition and flux. New transportation agencies have appeared within your lifetimes. Aviation of course is one of these. The more intensive use of pipe lines is another. You have heard much recently of competition by inland waterways and by the Panama Canal. Perhaps some of you know of the great inroads on railroad passenger traffic made by the private automobile, as well as by the motor bus. There is probably not a man in this hall without some knowledge of the competitive problem for the railroads that is presented by the motor truck, using the public highways for freight transport. Less apparent is the competition offered

by the increasing development of high-tension electrical transmission with its depressing effect upon the volume of coal otherwise necessary to be transported by the railroads, and the influence of the rapidly expanding network of natural gas transmission lines resulting in diminution in volume of coal required to be transported by the railroads to many metropolitan centers.

Keeping all of these factors in our minds, we can probably agree that the day is not far distant when each of these agencies will find its proper place in the transportation world. When that day arrives it may reasonably be expected to lessen somewhat the present difficult and often intangible problems presented to railroad management. We can further agree that the criterion which will determine the proper place of each transportation agency is that of the economics involved. What one of us believes that the permanent remedy lies in regulation or in legislation?

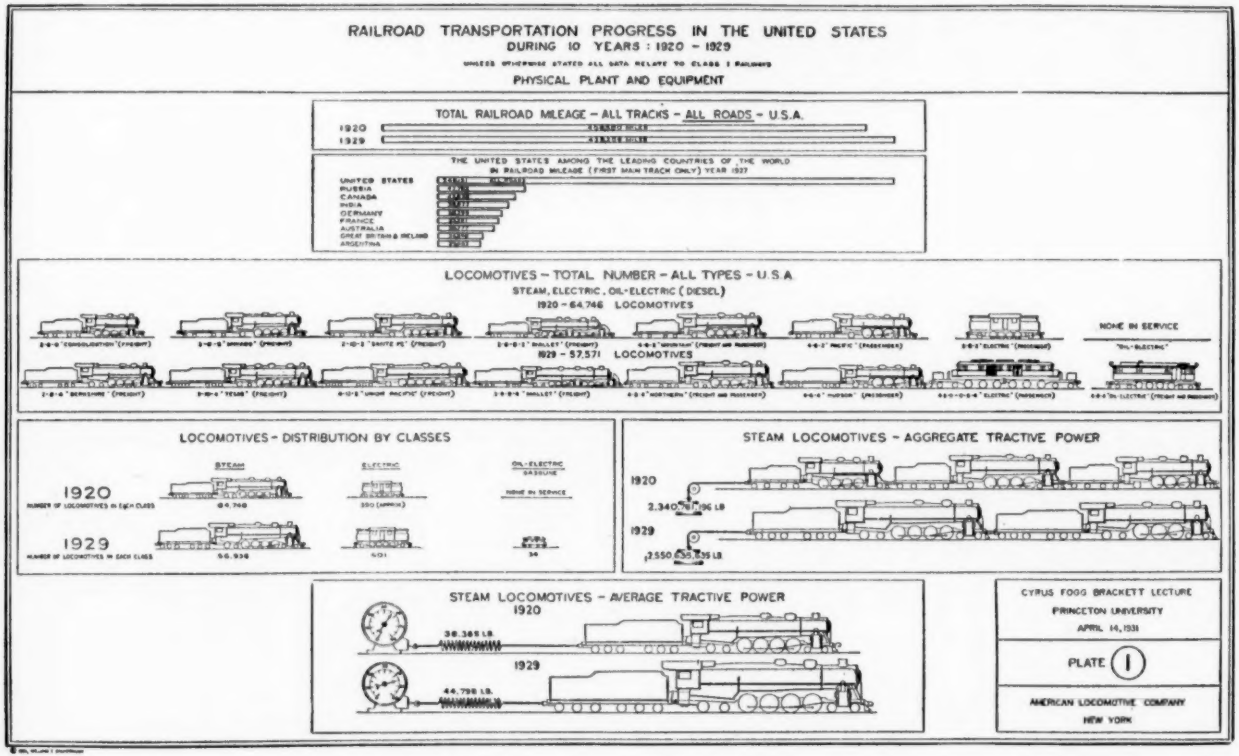
And now for the Charts!

Rather than minute description of each diagram or map, it will suffice to set down only such general comment or explanation as will give understanding of the significance of each.

PLATE ONE: RAILROAD MILEAGE AND LOCOMOTIVE DEVELOPMENT.

As you may expect, the increment in total railroad mileage for the United States during the ten-year period is small, amounting only to some 22,000 miles, or about 5 per cent. of the present total of approximately 428,000 miles. If this lecture had been delivered just fifty-five years ago, or in 1876, the elapsed decade's increment would have been a very different story. From 1869 to 1879, railroad mileage in the United States had almost doubled—this was at a time when Bell's "speaking telephone" was a thing of wonder! And Edison's lamp was just being born!

Referring again to the chart, you may be astonished at the present supremacy of the United States in railroad mileage, among the leading countries of the world. The comparative figures shown in terms of first main track are given for the year 1927, being the most recent available. It is interesting to observe the relative standing of the United States with


RAILROAD TRANSPORTATION PROGRESS IN THE UNITED STATES
DURING 10 YEARS : 1920 - 1929
UNLESS OTHERWISE STATED ALL DATA RELATE TO CLASS I RAILWAYS
PHYSICAL PLANT AND EQUIPMENT
TOTAL RAILROAD MILEAGE - ALL TRACKS - ALL ROADS - U.S.A.
1920
1929
THE UNITED STATES AMONG THE LEADING COUNTRIES OF THE WORLD
IN RAILROAD MILEAGE (FIRST MAIN TRACK ONLY) YEAR 1927
UNITED STATES
RUSSIA
CANADA
INDIA
GERMANY
FRANCE
AUSTRALIA
GREAT BRITAIN & IRELAND
ARGENTINA
LOCOMOTIVES - TOTAL NUMBER - ALL TYPES - U.S.A.
STEAM, ELECTRIC, OIL-ELECTRIC (DIESEL)
1920 - 64,746 LOCOMOTIVES
NONE IN SERVICE
1929 - 57,571 LOCOMOTIVES
LOCOMOTIVES - DISTRIBUTION BY CLASSES
STEAM
ELECTRIC
OIL-ELECTRIC GASOLINE
NONE IN SERVICE
1920
NUMBER OF LOCOMOTIVES IN EACH CLASS
64,746
350 (APPROX.)
1929
NUMBER OF LOCOMOTIVES IN EACH CLASS
60,936
401
34
STEAM LOCOMOTIVES - AGGREGATE TRACTIVE POWER
1920
2,340,706 LB
1929
2,550,835 LB
STEAM LOCOMOTIVES - AVERAGE TRACTIVE POWER
1920
38,385 LB.
1929
44,798 LB.
CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931
PLATE (1)
AMERICAN LOCOMOTIVE COMPANY
NEW YORK

250,000 miles of track in comparison with the next country on the list, namely Russia with about 48,000 miles. Coincidently, suppose we compare the United States' population of some hundred and twenty million with Russia's population of a hundred and fifty million, and we arrive at a figure of 480 inhabitants for every mile of first main line track in the United States as against over 3100 inhabitants for every similar mile in Russia; in other words, a ratio of nearly 7 to 1 in favor of America. This is an interesting measure from one angle, of the intensity of railroad development in the United States. Referring again to the chart, we see that Canada, India, German, France, Australia, Great Britain, and Argentina follow, in order.

In attempting to depict graphically the progress of railroad transportation in this country in terms of physical plant and equipment, much attention might be devoted to railroad line, structures, stations and terminals, signal equipment, shops, roundhouses, yards, bridges, tunnels—and all of the other many constituents which make up right-or-way and fixed plant. To do this would occupy more time that you have allotted me tonight and is essentially outside of the scope of the present discussion. I prefer therefore to concentrate attention upon that part of physical plant and equipment which has to do with motive power and rolling stock.

Under the latter categories, it is appropriate first to consider locomotives. Here again a surprise awaits you. There were some seven thousand *fewer* locomotives in service on the railroads of this country in 1929 than in 1920. What had been happening? Just this: as older motive power had been retired and new equipment made necessary, the new locomotives turned out by the American builders have had progressively greater *average capacity* than the units replaced or supplemented. Fewer locomotives do more work. As shown in the chart, the result has been that the aggregate tractive power of steam locomotives for all roads has increased from about two billion three hundred and forty million pounds in 1920, to over two billion five hundred and fifty million pounds in 1929. I believe you may be interested in the graphical representation, to scale, of the growth in average tractive power, as shown at the bottom of *Plate One*. Herein lies an effective

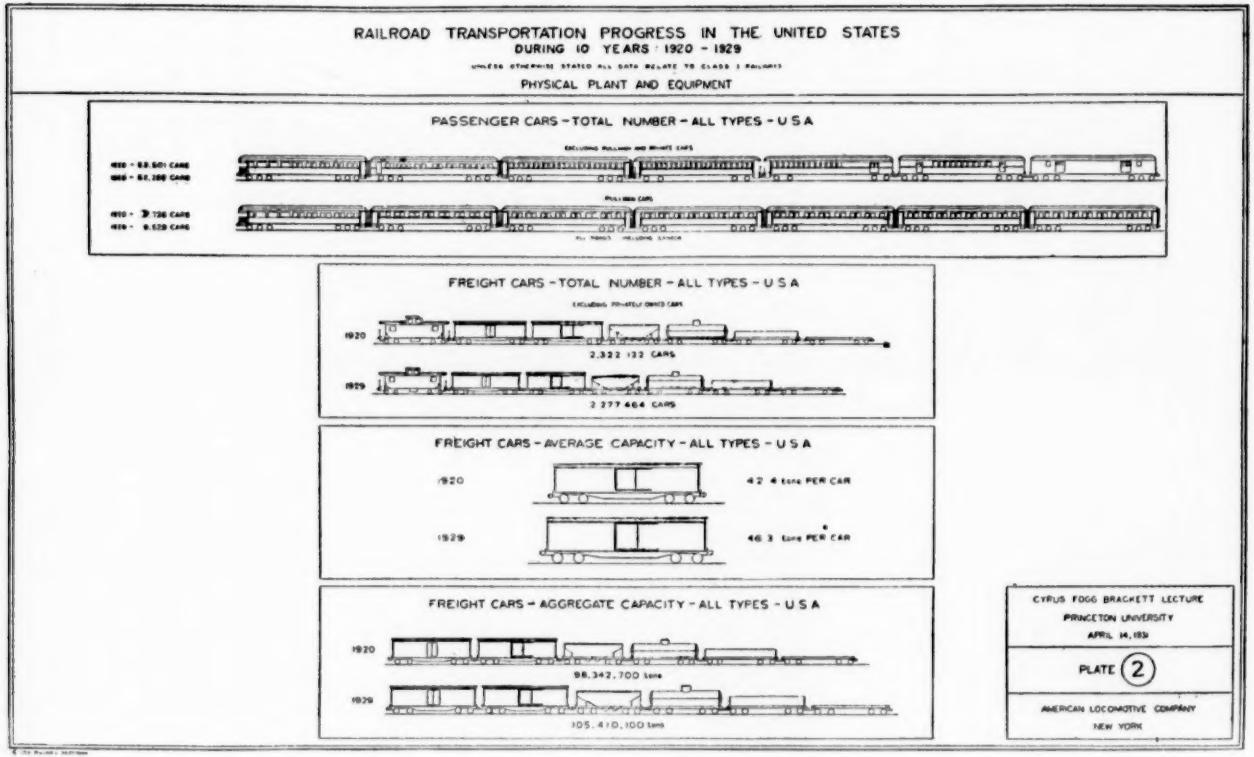
weapon for use by railroad management, on the railroads' battlefield. We will come back to that, later tonight.

Another influence has made its appearance in locomotive design and construction during the ten years. I refer to the Diesel-Electric locomotive, whose commercial birth in this country dates from the year 1925. Viewed in terms of number of units in service, the chart shows graphically the position of the Diesel-Electric locomotive in the transportation world today, compared with steam locomotives and electric locomotives. Much has been written in the technical press concerning the Diesel-Electric and its future. Its efficient adaptability to switching and yard service under certain conditions can be conceded. It is to this class of service that the majority of Diesel-Electric locomotives thus far built in the United States has been assigned. The steady improvement in design of the Diesel-Electric and the marked economies resulting therefrom, indicate a rapidly broadening field of usefulness.

Before dismissing *Plate One* let me call your attention to the graphical presentation of the various types of locomotive predominantly in service at the beginning and at the end of the decade we are considering. Too many of you the following explanation is already known, to others it may be informative. Take the first type which is shown at the left-hand of the chart and is designated: 2-8-0 "*Consolidation*" (*Freight*). It indicates the so-called Consolidation type of freight locomotives, having two leading truck wheels, eight driving wheels, and no trailing wheels. The next in order is designated: 2-8-2 "*Mikado*"(*Freight*). It indicates the so-called Mikado freight locomotives having two leading truck wheels, eight driving wheels, and two trailing wheels. The designations "2-8-0" and "2-8-2," etc., are in accordance with the Whyte Classification of Locomotives, and were originated by F. M. Whyte, formerly Mechanical Engineer of the New York Central and Hudson River Railroad. This readily understandable classification has been in wide use for upwards of twenty years.

PLATE TWO: ROLLING STOCK DEVELOPMENT.

Suppose as in the chart, we first consider passenger cars, separating the Pullman ownership. Here again you may be


RAILROAD TRANSPORTATION PROGRESS IN THE UNITED STATES
DURING 10 YEARS : 1920 - 1929
PHYSICAL PLANT AND EQUIPMENT
PASSENGER CARS - TOTAL NUMBER - ALL TYPES - U S A
FREIGHT CARS - TOTAL NUMBER - ALL TYPES - U S A
1920
2,322,122 CARS
1929
2,277,464 CARS
FREIGHT CARS - AVERAGE CAPACITY - ALL TYPES - U S A
1920
42.4 tons PER CAR
1929
46.3 tons PER CAR
FREIGHT CARS - AGGREGATE CAPACITY - ALL TYPES - U S A
1920
98,342,700 tons
1929
105,410,100 tons
CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931
PLATE 2
AMERICAN LOCOMOTIVE COMPANY
NEW YORK

surprised that the total number of passenger cars in service, excluding Pullman and privately owned equipment, has dropped during the ten-year interval. On the other hand, the total of Pullman equipment has increased by about 1,800. Progressively during the decade, emphasis by builders and users has been placed upon two characteristics: larger equipment and all-steel construction. Later herein, I wish to call your special attention to the drastic reduction in the volume of passenger traffic on the railroads during the decade—a reduction brought about by competition.

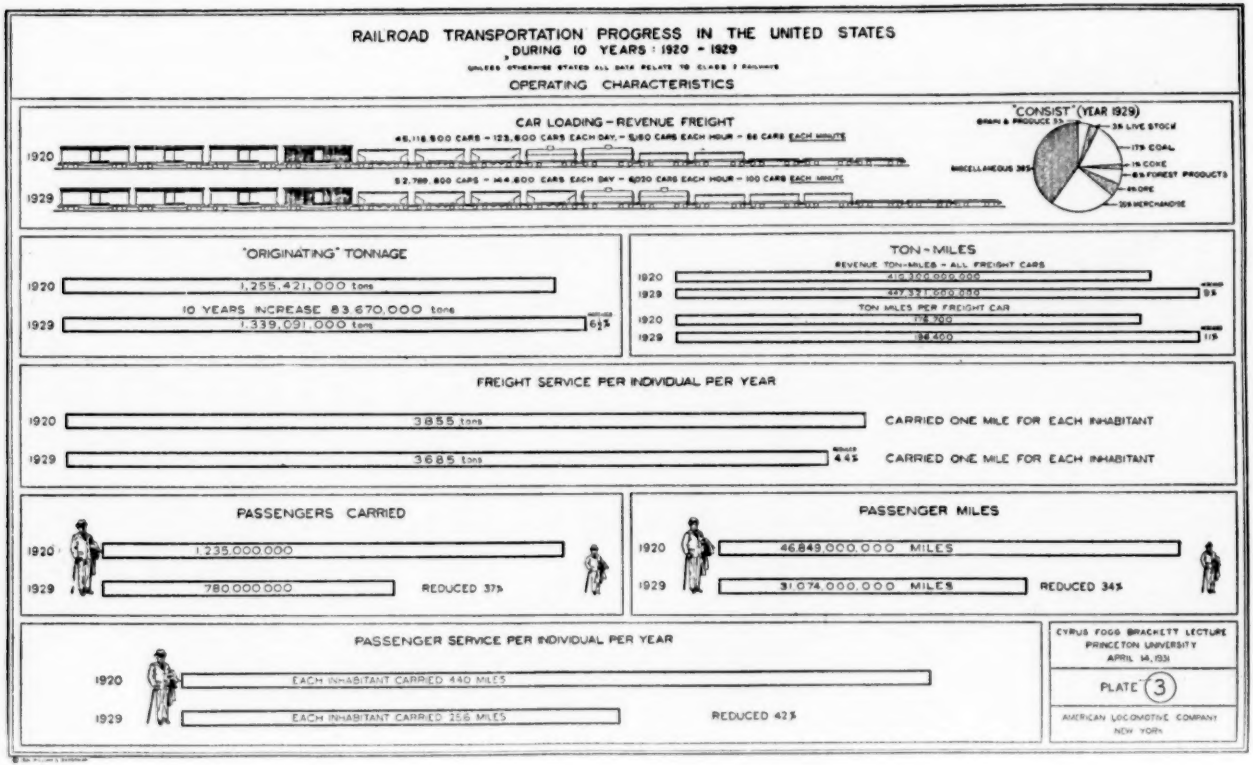
And now for freight cars: they similarly have experienced a reduction in number, and similarly an increase in average capacity, and coincidentally an increase in aggregate capacity. All of these features are shown clearly in the chart.

PLATE THREE: RAILWAY OPERATING CHARACTERISTICS (PHYSICAL).

In American business, two barometers have come to be recognized as accurate measures of commercial prosperity. Many of you are familiar with both of these yardsticks. They are respectively: the daily or weekly car loading on the railroads and the weekly or monthly kilowatt hour output of the public utility systems.

In the chart is given first the car loading in revenue freight during 1920, contrasted with that in 1929. Consider the immensity of the latter figures. A freight movement of nearly 53,000,000 cars in a year is difficult to grasp. We can get a much clearer conception of 145,000 cars per day. Better still, we can visualize 6,000 cars each hour. But we get keenest appreciation of what the railroads did in 1929, when we realize that an average of 100 cars were loaded with revenue freight *each minute*, during each hour of each day of the year, Sundays and holidays included!

The railroads of America transport every conceivable kind of commodity, of raw material, and merchandise. What the "*Consist*" was in 1929 is shown graphically in the chart. At once you single out the three leading items: Coal 17 per cent.; Merchandise 25 per cent.; and Miscellaneous 39 per cent. Perhaps you would have been inclined to guess that Grain and Produce would run higher than 5 per cent., and Livestock higher than 3 per cent.


RAILROAD TRANSPORTATION PROGRESS IN THE UNITED STATES
DURING 10 YEARS : 1920 - 1929
UNLESS OTHERWISE STATED ALL DATA RELATE TO CLASS I RAILWAYS
OPERATING CHARACTERISTICS
CAR LOADING - REVENUE FREIGHT
1920
45,116,600 CARS = 123,600 CARS EACH DAY, = 5,150 CARS EACH HOUR = 86 CARS EACH MINUTE
1929
52,780,800 CARS = 144,600 CARS EACH DAY = 6,030 CARS EACH HOUR = 100 CARS EACH MINUTE
"CONSIST" (YEAR 1929)
GRAIN & PRODUCE 5%
3% LIVE STOCK
17% COAL
5% COKE
6% FOREST PRODUCTS
4% ORE
35% MERCHANDISE
MISCELLANEOUS 25%
"ORIGINATING" TONNAGE
1920 1,255,421,000 tons
10 YEARS INCREASE 83,670,000 tons
1929 1,339,091,000 tons
REDUCED 6½%
TON-MILES
REVENUE TON-MILES - ALL FREIGHT CARS
1920 415,350,000,000
1929 447,321,000,000
INCREASED 8%
TON MILES PER FREIGHT CAR
1920 178,700
1929 198,400
INCREASED 11%
FREIGHT SERVICE PER INDIVIDUAL PER YEAR
1920 3855 tons CARRIED ONE MILE FOR EACH INHABITANT
1929 3685 tons REDUCED 4.4% CARRIED ONE MILE FOR EACH INHABITANT
PASSENGERS CARRIED
1920 1,235,000,000
1929 780,000,000 REDUCED 37%
PASSENGER MILES
1920 46,849,000,000 MILES
1929 31,074,000,000 MILES REDUCED 34%
PASSENGER SERVICE PER INDIVIDUAL PER YEAR
1920 EACH INHABITANT CARRIED 440 MILES
1929 EACH INHABITANT CARRIED 256 MILES REDUCED 42%
CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931
PLATE 3
AMERICAN LOCOMOTIVE COMPANY
NEW YORK

A second yardstick of railroad freight movement is presented in the chart: that of Originating Tonnage, per year. The increase of only 6 1/2 per cent. in ten years may surprise you. I suspect it equally has surprised many railroad Presidents. You can begin to be more sympathetic toward the problems which confront these men. For them there is present an ever-growing competition offered by other forms of transportation.

When railroad management seeks to secure an accurate picture of the physical performance of a particular road in freight movement, it scrutinizes two factors: "*ton-miles*" and "*ton-miles per train hour.*" The first of these is analyzed in this chart, integrated for all railroads. The result as you see is an increase of 9 per cent. in revenue ton-miles, and an increase of 11 per cent. in ton-miles per freight car, per year.

So far as the individual inhabitant of the United States is concerned, and remember that our population has steadily increased during the decade, we find a *reduction* of 4.4 per cent. in freight service per individual per year. The chart indicates that in 1929 nearly 3,700 tons of freight were carried one mile, *for each* inhabitant.

Four hundred and fifty million passengers *less*, or a reduction of 37 per cent. in number of passengers carried per year, constitutes a problem well-nigh staggering to any transportation organization. In a later chart we will see what this has meant to the railroads in dollars and cents, per year.

Occasionally our visitors from Abroad, particularly when on the eminence of the lecture platform, have accused Americans of being illogical. We must concede that it is something of a paradox that the reduction in *passenger miles* during this decade should have amounted only to 34 per cent., rather than be in closer agreement with the 37 per cent. reduction in number of passengers carried, as just referred to. The inference obviously is that the average length of passenger haul is somewhat greater today. In which connection it can be said that aviation may develop as a future competitor to be reckoned with in long-haul, or relatively long-haul passenger transport.

Had this lecture been delivered 55 years ago tonight, I would proudly have shown you how closely population increase during ten years was reflected in increased railroad

passenger transportation service, per capita. Today, however, because of competing forms of transportation, our chart shows a reduction of 42 per cent. in passenger service, per individual, per year. In 1920, the service rendered was equivalent to each inhabitant of the United States being carried 440 miles. In 1929, the figure was reduced to 256 miles.

PLATE FOUR: RAILWAY OPERATING CHARACTERISTICS (REVENUES AND TAXATION).

There may be many here tonight who have at their finger tips what is the present amount of the national debt of the United States. In round numbers, it is seventeen billion dollars. In 1929, railroad revenues aggregated six billion two hundred and eighty million dollars, or nearly 37 per cent. of the nation's indebtedness. Naturally, the bulk of this great slice of the country's yearly wealth was derived from freight service. As shown in the chart, about four billion eight hundred million dollars come from that source. Passenger revenue aggregated about nine-tenths of a billion.

The railroad executive, confronted as he is by the factors of growing competition, has always before him the problem of railroad operating expenses. For him there has been little opportunity to better the financial picture through increased tariffs, either freight or passenger. The trend has been toward lower rates rather than higher. Railroad management during the decade has accomplished surprising results in progressive reduction of operating expenses. The chart in detail tells the story. Again we are dealing with large figures. Operating expenses have been reduced from five billion eight hundred million dollars in 1920 to four billion five hundred million in 1929—a reduction of some 22 per cent.

Undoubtedly all present here tonight have followed the public utterances of many of the leaders and spokesmen for the common carriers during several years past, in respect to a problem that has assumed grave significance—a problem more concerned with the realm of politics than the realm of railroading. The burden of taxation upon the roads is a source of increasing concern to those responsible for the continued existence of their properties. Our chart shows the growth in volume of taxation. In 1929, $1.00 was paid in taxes for every $1.24 paid in cash dividends. In the chart,

RAILROAD TRANSPORTATION PROGRESS IN THE UNITED STATES
DURING 10 YEARS : 1920 - 1929

UNLESS OTHERWISE STATED ALL DATA RELATE TO CLASS I RAILWAYS

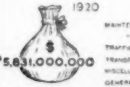
OPERATING CHARACTERISTICS

RAILROAD REVENUES

DIVIDED AS FOLLOWS:	1920
FREIGHT	$4,328,000,000
PASSENGER	1,289,000,000
MAIL	182,000,000
EXPRESS	144,000,000
SWITCHING	49,000,000
MILK	26,000,000
DINING CARS, ETC	35,000,000
EXCESS BAGGAGE	9,000,000
ALL OTHERS	146,000,000

DIVIDED AS FOLLOWS	1929
FREIGHT	$4,826,000,000
PASSENGER	874,000,000
MAIL	151,000,000
EXPRESS	148,000,000
SWITCHING	69,000,000
MILK	36,000,000
DINING CARS, ETC	35,000,000
EXCESS BAGGAGE	5,000,000
ALL OTHERS	136,000,000

RAILROAD OPERATING EXPENSES



DIVIDED AS FOLLOWS:	1920
MAINTENANCE OF WAYS & STRUCTURES	$1,033,000,000
" " EQUIPMENT	1,390,000,000
TRAFFIC EXPENSE	78,000,000
TRANSPORTATION EXPENSE	2,004,000,000
MISCELLANEOUS INCLUDING DINING CARS	63,000,000
GENERAL	167,000,000

DIVIDED AS FOLLOWS:	1929
MAINTENANCE OF WAYS & STRUCTURES	$835,000,000
" " EQUIPMENT	1,203,000,000
TRAFFIC EXPENSE	136,000,000
TRANSPORTATION EXPENSE	2,080,000,000
MISCELLANEOUS INCLUDING DINING CARS	58,000,000
GENERAL	180,000,000

RAILROAD TAXATION

$745,000 PER DAY

$1,087,000 PER DAY

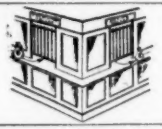
1923 TAXATION PER HOUR
$45,300

NUMBER OF RAILROAD EMPLOYEES

1920 — 2,023,000

1,661,000 — REDUCED 18%

1929



OPERATING RATIO

1929	
FREIGHT SERVICE	66.96
PASSENGER SERVICE	90.14
COMBINED SERVICE	71.7

CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931

PLATE (4)

AMERICAN LOCOMOTIVE COMPANY
NEW YORK

note the 1929 railroad tax bill of nearly four hundred million dollars and we see that this is equivalent to upwards of a million dollars *a day*, and over $45,000 an hour!

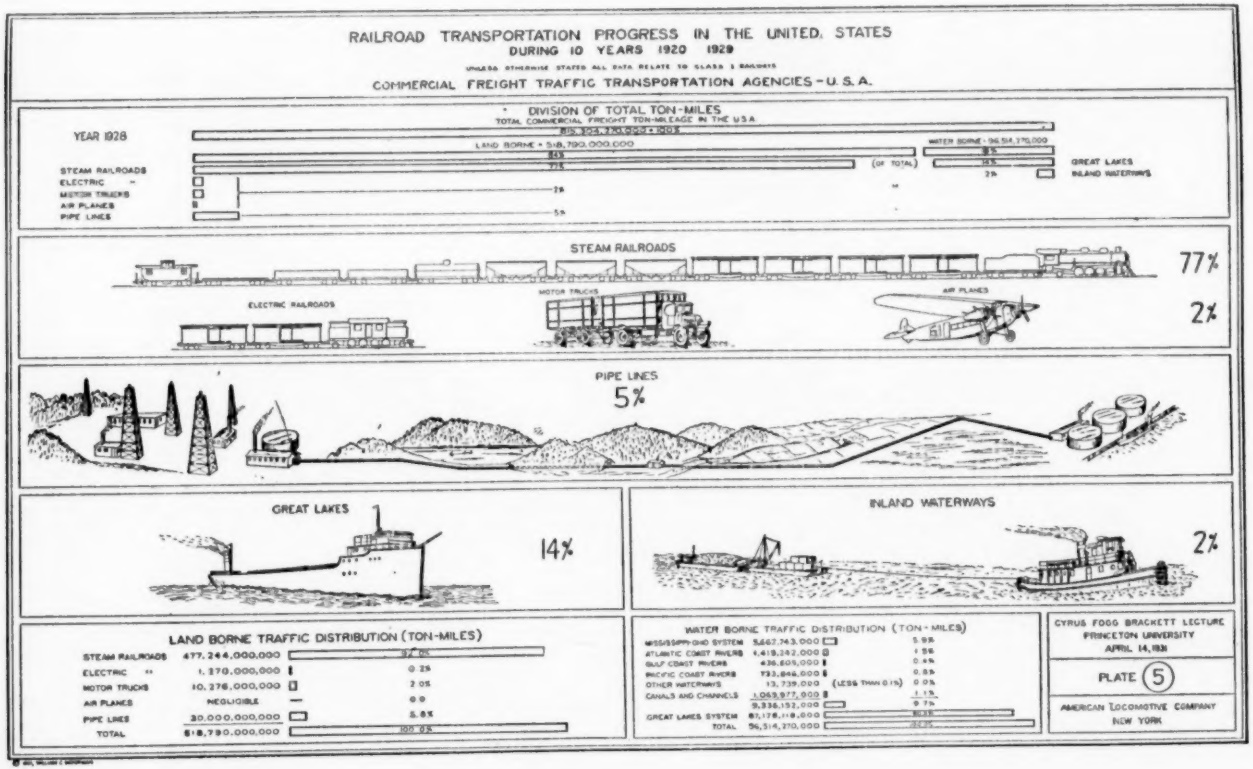
The world's greatest railroad establishment naturally must comprise a huge household. The number of railroad employes is not a negligible fraction of our total population. The chart gives the figures, and let me exemplify them by saying that the present (1929) personnel is equivalent to 41 out of every 100 men in the troops of the United States under arms during the World War.

There is a law in physics—the law of action and reaction. Railroad presidents are no exception to the operation of this law. In some directions they can and do "deplore"; in others they can "point with pride"! Any railroad president is human enough to point with pride to a notable achievement in progressive betterment of his *operating ratio!* As in the chart, operating ratio is defined as the ratio between "Operating Costs" and "Operating Revenue." One of the goals of management is towards steady reduction of this ratio. The roads are to be congratulated upon what has been accomplished. It has meant much to their financial condition.

PLATE FIVE: TRANSPORTATION AGENCIES.

What today are the principal freight transportation agencies in the country? Obviously these: the steam railroads, the electric railways, motor trucks, airplanes, pipe lines, and water-borne agencies. The latter are divided between the inland waterways and the Great Lakes. Transatlantic, transpacific, coastwise, intercoastal, and Panama Canal traffic are not included in the picture this chart paints. Commercial freight traffic in the United States by the transportation agencies shown is seen to amount to 615 *billion* ton-miles during 1928, the most recent figures available.

Without analyzing the details in the chart, it is interesting to observe the following percentages: Steam railroads, including electrified operation, 77 *per cent.*; electric railroads, motor trucks and airplanes, 2 *per cent.*; pipe lines, 5 *per cent.*; and water-borne traffic, including Great Lakes and inland waterways, 16 *per cent.*


RAILROAD TRANSPORTATION PROGRESS IN THE UNITED STATES
DURING 10 YEARS 1920 1929
UNLESS OTHERWISE STATED ALL DATA RELATE TO CLASS 1 RAILROADS
COMMERCIAL FREIGHT TRAFFIC TRANSPORTATION AGENCIES - U.S.A.
DIVISION OF TOTAL TON-MILES
TOTAL COMMERCIAL FREIGHT TON-MILEAGE IN THE U.S.A.
YEAR 1928
BIG 504,230,000,000 TON MILES = 100%
LAND BORNE - 518,790,000,000
WATER BORNE - 96,514,270,000
STEAM RAILROADS
ELECTRIC "
MOTOR TRUCKS
AIR PLANES
PIPE LINES
(OF TOTAL)
GREAT LAKES
INLAND WATERWAYS
STEAM RAILROADS
77%
ELECTRIC RAILROADS
MOTOR TRUCKS
AIR PLANES
2%
PIPE LINES
5%
GREAT LAKES
14%
INLAND WATERWAYS
2%
LAND BORNE TRAFFIC DISTRIBUTION (TON-MILES)
STEAM RAILROADS 477,244,000,000 92.0%
ELECTRIC " 1,270,000,000 0.2%
MOTOR TRUCKS 10,276,000,000 2.0%
AIR PLANES NEGLIGIBLE 0.0
PIPE LINES 30,000,000,000 5.8%
TOTAL 518,790,000,000 100.0%
WATER BORNE TRAFFIC DISTRIBUTION (TON-MILES)
MISSISSIPPI-OHIO SYSTEM 5,667,743,000 5.9%
ATLANTIC COAST RIVERS 1,419,242,000 1.5%
GULF COAST RIVERS 430,605,000 0.4%
PACIFIC COAST RIVERS 733,866,000 0.8%
OTHER WATERWAYS 13,739,000 (LESS THAN 0.1%) 0.0%
CANALS AND CHANNELS 1,069,977,000 1.1%
9,336,152,000 9.7%
GREAT LAKES SYSTEM 81,178,118,000 84.1%
TOTAL 96,514,270,000 100.0%
CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931
PLATE (5)
AMERICAN LOCOMOTIVE COMPANY
NEW YORK

It is probably fair to say that the 2 per cent. allocated to electric railroads, motor trucks, and airplanes in 1928 has experienced progressive increase during the succeeding years. The trend in motor truck transport has been steadily upward. It may interest you to know that motor truck registration shows an extraordinary increase since 1915. The number registered in the United States that year was 136,000; the number registered in 1928 was 3,114,000. Incidentally, the number registered in 1905 was 600 trucks! The year 1905 was a banner year in locomotive building in this country. It was the peak for the present century.

On the other hand, and again in fairness to the motor truck and the airplane, it must be remembered that the building of these competitive carriers has resulted in an immense tonnage of raw material and finished product transported by the steam railroads. Railroad management has been fair in giving recognition to these facts.

PLATE SIX: TERRITORIAL GROUPING OF RAILROADS.

Whenever I have occasion to scrutinize a map of our forty-eight States there comes vividly to mind the romance back of the indomitable struggle of the pioneers, in pushing our country's frontier further and further westward. First trails, then roads, then the railroads followed these pioneers. We can think of our great transcontinental rail lines today as enduring monuments to the pioneer spirit of the early leaders of America. Can we not attribute to them a veritable genius of Engineering? How completely the country is covered by the railroads is suggested by the data made part of the map.

Already we have seen that no other country in the world approaches the nearly quarter of a million miles of railroad tracks which this country has; no other country has nearly so many locomotives; no other country approaches the number of cars needed under normal conditions.

Briefly let us get our perspective of the geographical immensity of the United States, with its nearly three million square miles of area—a country whose national consciousness immeasurably has been knit closer together during your own lifetimes. I refer of course to the progress of long-distance telephone and radio communication. You know the two

TERRITORIAL RAILROAD GROUPING - U.S.A.

	TOTAL U.S.A.	EASTERN DISTRICT	SOUTHERN DISTRICT	WESTERN DISTRICT
MILEAGE	249131	58158	50452	139521
PERCENT OF TOTAL IN U.S.A.	100%	24%	20%	56%
LOCOMOTIVES	57571	24947	10809	21815
PERCENT OF TOTAL IN U.S.A.	100%	43%	19%	38%
PASSENGER CARS	52359	25930	8032	18297
PERCENT OF TOTAL IN U.S.A.	100%	50%	15%	35%
FREIGHT CARS	2277464	1042420	418182	816862
PERCENT OF TOTAL IN U.S.A.	100%	46%	18%	36%

ALL FIGURES 1921

1929

geographical yardsticks of our country's dimensions: New York to San Francisco nearly 2,700 miles, and the North Dakota-Canadian Boundary to the Texas-Mexican Boundary at the Lower Rio Grande Valley some 1,700 miles.

For purposes of administration the Interstate Commerce Commission has divided the country into districts and regions, shown in the map. The distribution by districts, of railroad mileage, of locomotives, and of cars is given in the tabulation. Some of this information will interest you.

Not the least important contribution by the locomotive on this battlefield of three million square miles, has been the ability of modern motive power to level out the country. Today's locomotive balks at no mountain grades. Sustained speed is possible with heavy loads on mountain divisions, and as we shall see the longer engine runs now a matter of usual practice have been a telling factor in promoting further the economy of operation.

On the map are located some of the more important railroad centers.

PLATE SEVEN: CAPITAL EXPENDITURES BY RAILROADS.

You should know that the railroads have not been standing still since the World War. They have been engaged in an intensive program for physical improvement of their properties. In the chart you see that over seven billion dollars of capital expenditures were made from 1922 to 1930. During 1923 alone, over a billion dollars were spent. It has been part of a national program of spending money to save money. By which I mean the expenditures had primarily for their purpose to increase the efficiency of operation. It is likely that there would be reasonable consensus of opinion among railroad presidents today that the results secured, in tremendously improved efficiencies, lower operating ratios, a better condition of railway property, and vastly improved service to the public, have justified this large investment in plant capital account. The chart gives the distribution of these capital expenditures.

You may share in my wonder that only 11 per cent. of the expenditure was for locomotives. The locomotive is the heart of the railroads' being! In the light of subsequent events, the expenditure was too small.

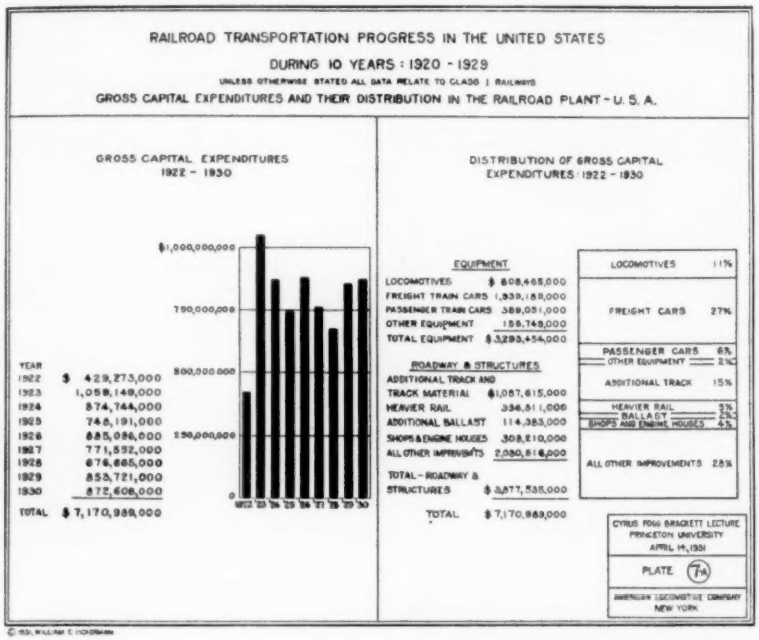


PLATE EIGHT: FREIGHT SERVICE DURING TEN YEARS.

The backbone of railroad operation always has been freight movement. So far as can be foreseen this situation will continue. Four characteristics of freight service operation during the ten years are analyzed, namely: freight tons per average train, aggregate tonnage moved, aggregate coal burned, and aggregate locomotive tractive power.

With an increase of 13 per cent. in freight tons per average train, an 8 per cent. greater volume of revenue tonnage has been moved, with a 10 per cent. saving in coal burned and a 17 per cent. increase in locomotive tractive power. Do not misunderstand the significance of these figures. Bear in mind that the tonnage moved was that which the public offered, and in the way and at the times the public offered it. Moreover, bear in mind that the locomotive capacity represented by the tractive power figures could have given even better account of itself with a larger volume of tonnage offered. However and despite these limitations, marked improvement is noted in the loading of trains and in the consumption of fuel. A 10 per

cent. yearly saving in coal burned by the railroads is no little contribution by them to the conservation of our natural resources. Remember that the figure of some 800 tons of freight per train is an *average* figure, giving effect to all freight train movement throughout the United States, both loaded and light, and on all roads. It is not rare for a modern freight locomotive to haul trains weighing up to 10,000 tons. You will understand how low is this *average* figure of 800 tons per freight train, when I tell you that one passenger section of the *20th Century Limited*, between New York and Chicago, may weigh upwards of 1,000 tons.

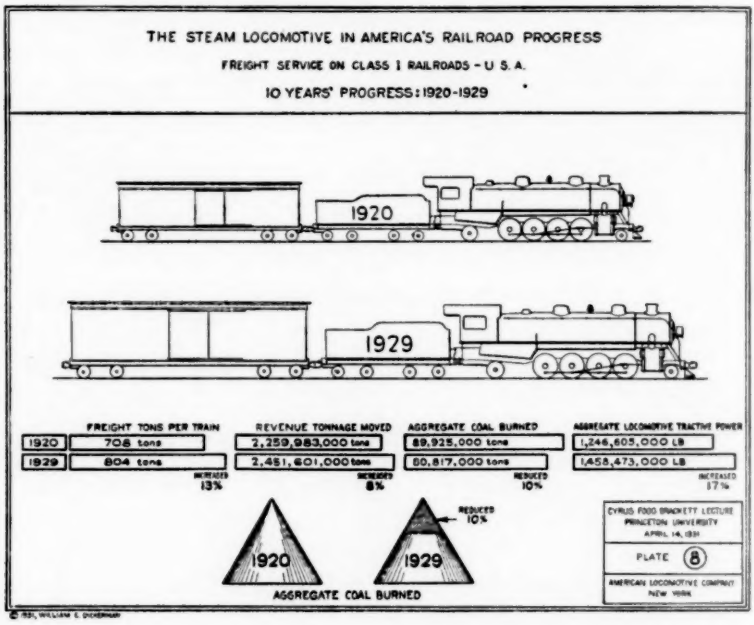
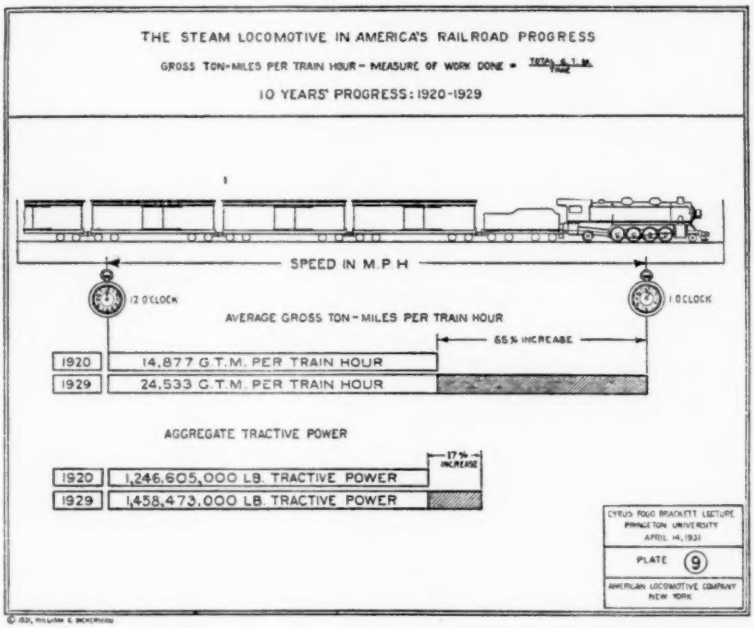


PLATE NINE: GROSS TON-MILES PER TRAIN HOUR.

And now we can get our feet on the ground! Up to this point we have been discussing together the broad vision of the general picture. Now we can look into that searching yardstick of freight movement which is acknowledged as the ultimate criterion of performance and capacity. Gross ton-miles per *train hour* takes account not only of the volume of tonnage

moved but also the time element expressed in speed. It gives effect to tonnage volume and miles hauled, per train hour.

In the early days of railroading little attention was deemed necessary to be given to the element of time, and efforts were concentrated on increasing tonnage of individual trains, almost regardless of speed. Slow freights were the result. Physical and economic influences have combined to change the situation. Track capacity in general has not increased with increasing freight traffic. The movement of perishables



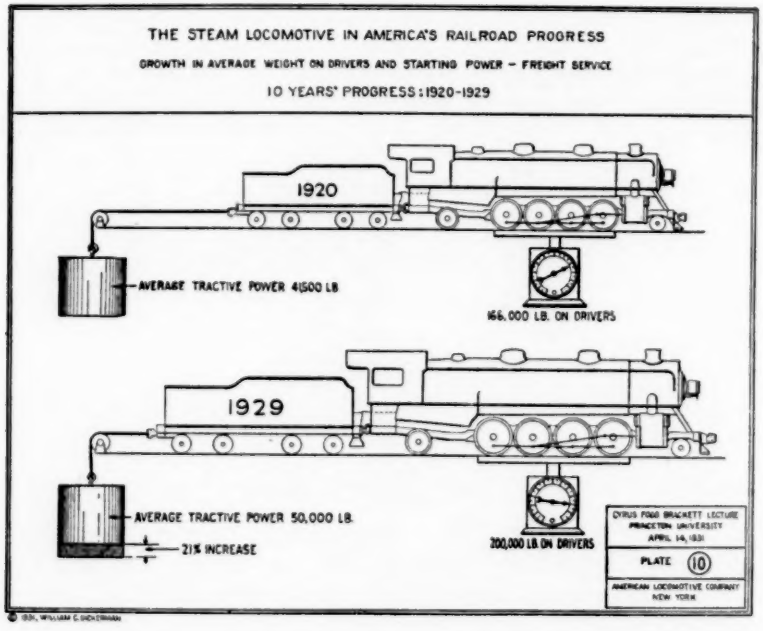
vastly has expanded. The rank and file of the shipping public has required schedules previously unheard of. These very schedules, as already mentioned, have enabled manufacturers and merchants to reduce inventories, and have promoted the popular hand-to-mouth buying habit. At the same time, the railroads have found it more profitable to handle freight movement more expeditiously.

The marked progress in railroad operating performance, as measured by the improvement in average gross ton-miles per train hour is the reflected influence of all these factors.

Our chart gives graphically the results during the ten years. A 65 per cent. increase in average gross ton-miles per train hour was secured with an increase of only 17 per cent. in aggregate tractive power. Bigger, better, faster locomotives have been built. These have been utilized more efficiently, more satisfactorily, and more profitably by the railroads.

PLATE TEN: WEIGHT ON DRIVERS VS. STARTING POWER.

In order to gain understanding of the part which the locomotive is playing on the railroads' battlefield, you will pardon certain technical references found in this and the two succeeding charts.



We can concede that the primary function of a locomotive is to pull. Its ability to pull, or its tractive power, is a function of its own weight, or at least its weight on drivers. Theoretically, the locomotive builders might continue almost indefinitely to increase the weights of locomotives they are

turning out. But this is not possible in practice. At least two effective obstacles are met. First, the weight of rail as limiting the permissible weight on drivers, and secondly, the limitations imposed by strength of bridges and other structures along the right-of-way. Besides, the clearance diagram must be observed in all designs, else bridge, tunnel, and other clearances would be violated. So a most important problem in locomotive design is to secure adequate tractive power from permissible weight on drivers.

Our chart attests the measure of achievement in this direction, secured during the ten years. Shortly hereafter we will discuss the significance to the railroads of an increase in average tractive power of an order of magnitude of 21 per cent. Other things being equal, increased tractive power means heavier trains.

PLATE ELEVEN: WEIGHT ON DRIVERS AND CAPACITY—FREIGHT.

Until now in tonight's discussion we have considered overall and average performance as based upon authoritative records of the American Railway Association, the Bureau of Railway Economics, and the Interstate Commerce Commission. Unfortunately and unavoidably all such records to date have concerned themselves with *maximum* tractive power, so far as capacity is involved.

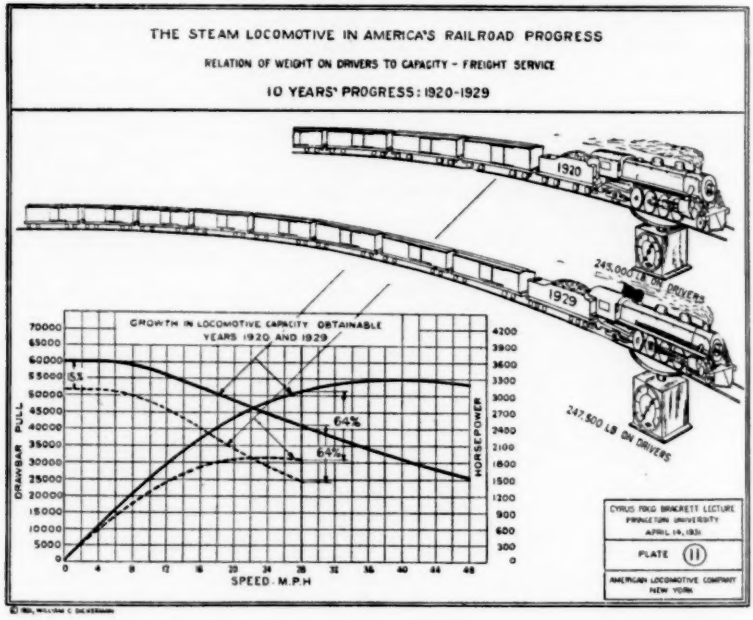
It is important here to draw a vital distinction, one which perhaps is not fully understood even by all rail officials. I have emphasized it in previous public utterances. The distinction is this: *a true measure of locomotive performance, so far as capacity is concerned, is found in the tractive power developed at usual operating speeds for the service intended, rather than found in maximum tractive power at starting.*

The substantiating purpose of our chart is to cite chapter and verse in two actual instances of heavy duty freight locomotives, one type in service in 1920 and the other in 1929, but both on the same railroad and in the same class of service. The comparison illustrates admirably the distinction I have just drawn.

The earlier locomotive had a weight on drivers of 245,000 pounds. In its curves of performance, shown dotted, the locomotive developed a drawbar pull *at starting*, of 52,000

pounds. At 28 miles an hour, which is a good average operating speed for freight service today, the engine developed a drawbar pull of 25,000 pounds with an output of 1,900 horse power.

The locomotive of 1929, whose performance is indicated in curves shown solid, developed a drawbar pull *at starting* of 60,000 pounds, or a 15 per cent. increase over the earlier locomotive. This was accomplished with an increase of about one per cent. in weight on drivers. The 1929 locomotive at



28 miles per hour develops a drawbar pull of 41,000 pounds, or 64 per cent. more at that speed than the earlier locomotive. It is the drawbar pull at usual operating speed which counts!

Contrast often best tells a story! This locomotive of 1929 is no more powerful *at starting* than many locomotives built in 1920, or even built many years earlier. However—and this is important for you to remember—the drawbar pull of this locomotive of 1929, throughout an operating range of speed from say 20 to 40 miles per hour which is present-day

practice, represents an immeasurable improvement over these earlier locomotives of higher starting power. Herein lies a major contribution to the sinews of war on our battlefield.

Indeed I could cite you a design developed as early as 1900, wherein the starting power attained in actual field tests was identical, namely 60,000 pounds. However, if that 31-year old locomotive were today to be placed in main line service on modern freight schedules, it would fall by the wayside.

What is the practical application of all of this? Freight schedules in heavy service, making far faster time and without reducing tonnage! How is it you get your apricots so fresh from California, your cantelopes from the Imperial Valley, your grapefruit from the Lower Rio Grande Valley, your oranges from Florida, your strawberries and early vegetables from Louisiana, your peaches from Georgia, your early asparagus from the Carolinas, and your berries from the Pacific Northwest and New England? Fast freight schedules, on heavy trains, is the answer! Greater drawbar pull on faster operating schedules is the means.

PLATE TWELVE: WEIGHT ON DRIVERS AND CAPACITY—PASSENGER.

An exactly similar analysis is undertaken in this chart, as in the preceding, except that the engines are in passenger service. Both locomotives are actual cases, and the results are actual performance. In the present instance, the weight on drivers is nearly 5,000 pounds *less* in the 1929 locomotive than in the 1920, yet despite this lighter weight and due to progressive refinement in design, the newer locomotive develops 37 per cent. more drawbar pull at starting, and develops 139 per cent. more drawbar pull at passenger express speed of 60 miles per hour. Moreover, it hauls 15 Pullmans instead of 10. If offered, it can haul more than 15 Pullmans, on the particular runs for which it was built.

It takes little imagination to picture the advantages in passenger train movement when the motive power through constantly improved design can draw more Pullmans at no sacrifice in speed. It means a reduction in the number of sections on limited trains during times of heavy traffic. This reduces often the number of diners necessary. Every time you can consolidate two trains into one, you have effected an

equivalent addition to track capacity, over a particular division. Headway between trains can be increased, other things being equal. These are some of the advantages resulting from greater sustained capacity, in passenger motive power.

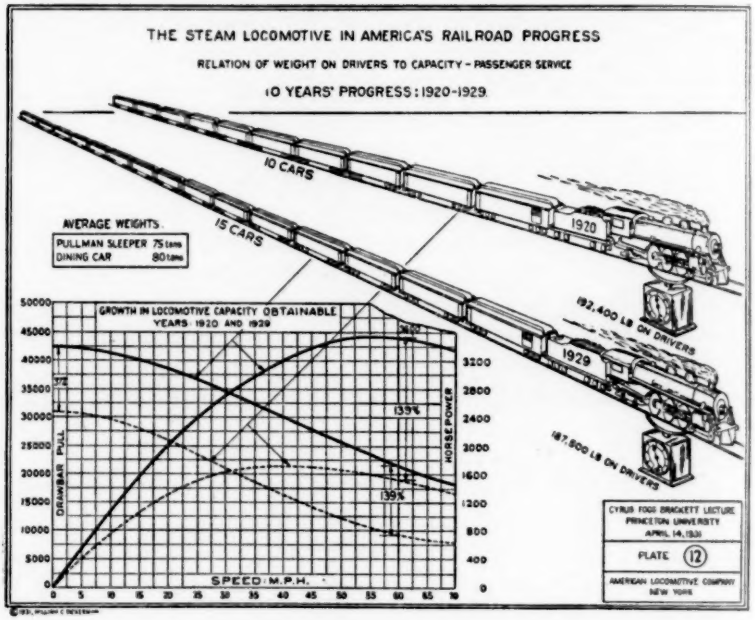


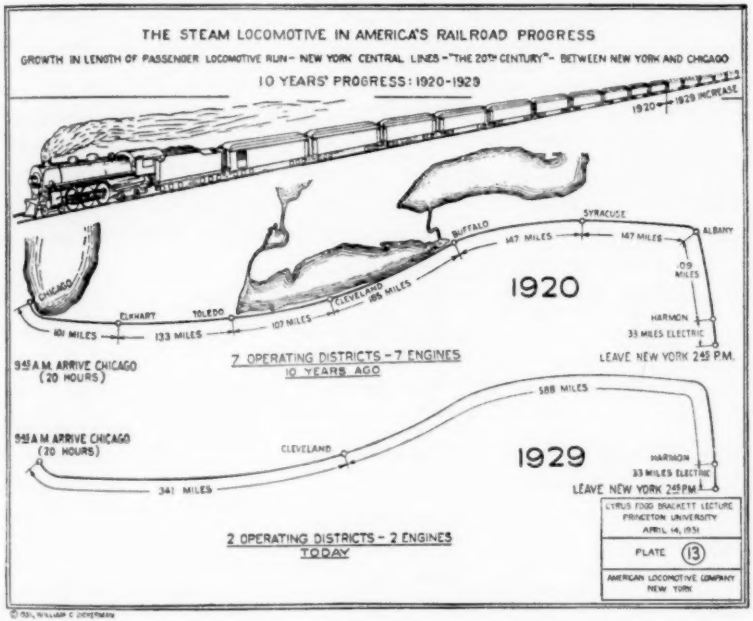
PLATE THIRTEEN: LONG ENGINE RUNS.

Extraordinary progress has been made by the railroads since the return of them of their properties on March 1, 1920, by the U. S. Railroad Administration. Far-reaching economic improvement has resulted from longer engine runs. The utilization factor of motive power, or to borrow a familiar term from the electric public utility industry—the "load factor," has been improved to a point which would have been regarded almost unbelievable ten years ago.

Longer engine runs are the accepted practice on almost every railroad in the United States, and in both freight and passenger service. The most striking instances naturally are those found in passenger runs.

Our chart takes as an actual example a passenger run in the East which is well known throughout the country. It is the

daily run of the *20th Century Limited* on the New York Central Lines between New York and Chicago. In 1920, just as today, this 29-year old, 20-hour train leaves New York at 2:45 P.M. and arrives in Chicago at 9:45 the next morning. But in 1920 no less than seven steam locomotives were used to make the 929-mile run from Harmon to Chicago. The respective runs of these seven engines were: from Harmon to Albany; to Syracuse; to Buffalo; to Cleveland; to Toledo; to Elkhart; and into the La Salle Street Station at Chicago. In 1929, the same



run and making the same schedule, is accomplished with two steam locomotives, namely: from Harmon to Cleveland; and from Cleveland to Chicago. Incidentally, but this is concerned with greater locomotive capacity rather than longer runs, the 1929 average train for the *Century* was very much heavier than the 1920.

Many other humanly interesting examples of longer engine runs could be cited. There is a classical passenger run on the Souther Pacific using an oil-burning locomotive, from Los Angeles into El Paso, a distance of 815 miles.

Another important and recent example is in the transcontinental passenger service on the Northern Pacific between St. Paul and the Pacific Coast, with only three engine districts. The longest of these is between Jamestown, North Dakota, and Missoula, Montana, a run of 904 miles. Five years ago there were 13 engine districts on the 1,900 miles between St. Paul and Seattle.

Similar but less extended progress has been made in longer runs for freight locomotives. A good example is the practice of the Chicago, Milwaukee, St. Paul and Pacific Railroad in operating freight locomotives in continuous service between Mobridge, South Dakota, and Harlowton, Montana, a run of 530 miles.

Time was when the generally accepted usage was to change the locomotive on the train every time you changed the operating crew. In fact on many roads a particular locomotive was allocated to a particular engineer. The physical limitations of the man limited the degree of utilization of his locomotive. Today the picture is completely changed.

You will find little inclination among operating executives to return to the old practice of shorter engine runs, either in passenger or freight service. Indeed the entire fabric of railway operating schedules for many roads is predicated upon present lengthened runs. In some instances, division points have been abandoned and the facilities changed over to other railway use. Few carriers have not availed themselves of these economies. Later tonight I shall refer to a mild debate which in railroad circles familiarly is called "Eggs to a Hen."

From a selfish viewpoint the locomotive builder might deplore the practice of longer engine runs as affecting the demand for new power. However, all of us are big enough to recognize that whatever practice in railroad operation or elsewhere is founded upon sound economic principles, is ultimately of the greater benefit to all concerned.

An outstanding claim, made a generation ago, for the electric locomotive was its ability to operate on longer engine runs. The steam locomotive has succeeded in meeting that challenge, far beyond what would have been imagined twenty years ago. You may particularly be interested that the Northern Pacific Railway took a modern freight locomotive,

without any unusual preparation, attached it to a heavy freight train and ran that one locomotive from Seattle, over three mountain ranges, through to St. Paul without change, a distance of nearly 2,000 miles. The locomotive was taken out of pooled freight service, where it had been operating steadily for five months. On this transcontinental record run, no time was spent giving attention to the fire or ash pan at terminals, and no mechanical difficulties were encountered enroute.

PLATE FOURTEEN: AVERAGE AGE OF LOCOMOTIVES.

How old is Ann! One of the much-discussed and considerably debatable subjects in transportation circles is that of the age of locomotives in service on the quarter of a million miles of railroads in this country! It has been found impossible to secure from any source completely exact information. Because of its importance as one angle in tonight's discussion, I have attempted to analyze available information, both from governmental sources and from the railroads themselves, and here present for the first time a chart which crystallizes the results of this study by American Locomotive Company. It may be taken as a close approximation.

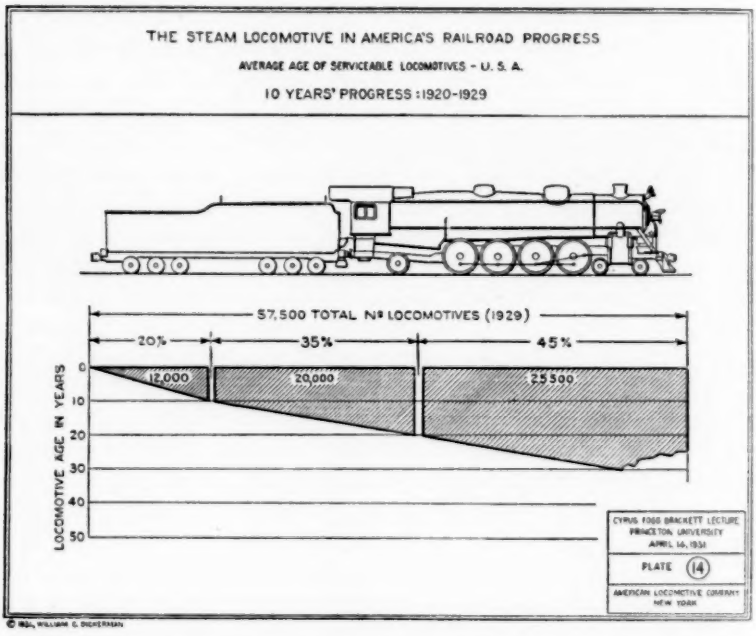
The chart shows that some 12,000 of the serviceable locomotives in the United States in 1929, or 20 per cent. of the total, were ten years old or less; that about 20,000 locomotives, or 35 per cent., were over ten years old and less than twenty; and that some 25,000 locomotives, or *45 per cent.*, were over twenty years old.

In the chart, we have not attempted to continue to its conclusion the diagonal line which you will observe is broken off at about 32 years in age. Our reason is because of the fact that there are some "museum pieces" in isolated service whose birth goes back almost to the Centennial of 1876. Were it not frivolous, I truthfully might cite for you one distinguished old teakettle, still puffing in active but unimportant service, whose nameplate bears the date: "A.D. 1879"!

But seriously, we can agree that a problem exists for railroad management in the operation of nearly 50 per cent. of their motive power having an age of 20 years or more. It is a problem which through future replacement by more modern

and vastly more efficient motive power holds opportunity and promise of solution, at a time when normal traffic conditions will have been restored.

Correlatively, let me call your attention to the substantial sums that have been spent by railroad managements upon the maintenance and rebuilding of old locomotives. We shall see what great economies in maintenance and in operation can be realized by the introduction of modern, efficient locomotives. In many instances these economies can be attained at no cost



to the railroads, because of the fact that the new locomotives through savings will pay for their own first cost, their maintenance and contingent expenses, and at the same time return a handsome profit to the railroads. The capital structure of the common carrier need not be impaired since the locomotive builders are prepared to handle all financing.

Indeed it has been proposed that there be developed for and by the railroad managements a budget plan, looking toward the gradual elimination of old and obsolete locomo-

tives, through a process of annual retirements and annual purchases. Such a plan would result in a more constant demand year by year upon the resources of the locomotive builders, and might reasonably be expected to result in a lower cost per locomotive unit.

Looking ahead, herein lies wide opportunity for the experience and genius of builder and railroad management to add mightily to the future sinews of war—on the railroads' battlefield.

PLATE FIFTEEN: WHAT REPLACEMENT MEANS!

Generalities may attain virtue in any discussion. However, a less gracious audience than is mine tonight might easily demand concrete facts. Such demand would be entirely justified. I propose to meet the challenge. I am prepared to show what can be accomplished in dollars and cents savings through the replacement of older equipment by modern motive power.

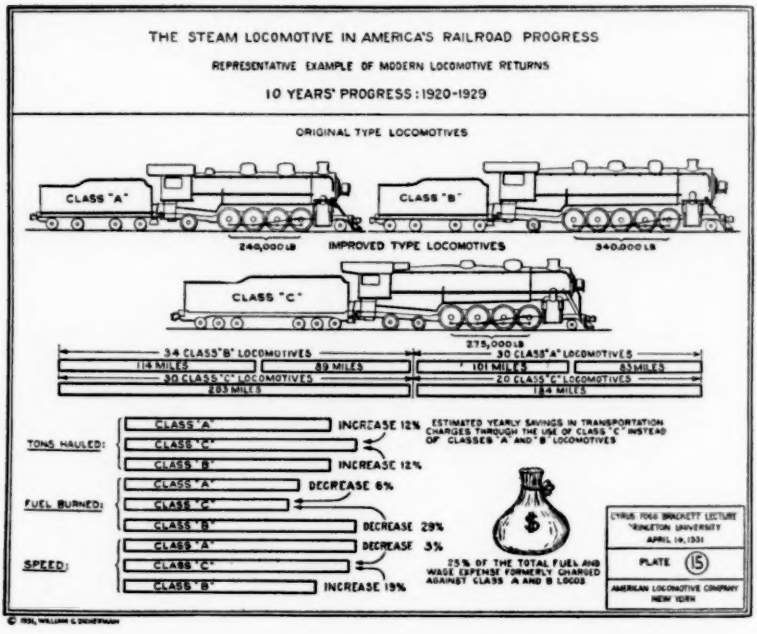
I have some knowledge of your electric public utility industry. I am acquainted with its great leaders in this and nearby districts. I have seen the great steam electric plants spring up over-night during the last decade in Pennsylvania and New Jersey. I have seen the great hydro-electric plants of Conowingo and Safe Harbor come into existence. These managements, my friends, have not hesitated to replace their prime mover equipment with more efficient apparatus as developed. The economic analogy holds good in the field of railroad motive power.

Out chart is an actual example taken at random from many. It represents the dollar and cents savings to a well known railroad through the replacement of older motive power by modern and highly efficient locomotives.

The facts were these: 30 locomotives, which for convenience we will designate as Class "A," were in freight service on divisions of 101 and 83 miles respectively; 34 locomotives, which similarly we will designate as Class "B," were in service on adjacent divisions of 114 and 89 miles respectively. The problem was to replace these 64 engines by a design of locomotive which would handle no less tonnage, on faster schedule, and over two divisions combined, namely: 184 and 203 miles,

with a performance that would yield sufficient return on the new investment to warrant the replacement of the older motive power.

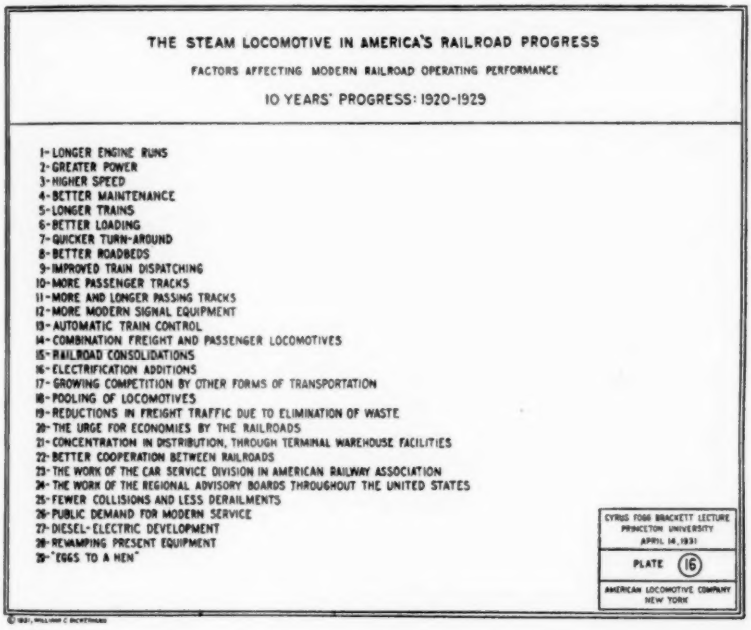
The design which was developed is such that 50 of the new locomotives designated for convenience Class "C," have more than filled each one of the requirements. The example combines four vital characteristics which promote better railroading. They are: greater power, higher speed, longer engine runs, and reduced fuel consumption. Don't forget that next to wages, fuel is the largest single item of expense in operating a railroad.



The chart shows that a 25 per cent. saving in transportation expense is possible through the replacement of 64 Class "A" and Class "B" locomotives, by 50 Class "C" locomotives. This does not include savings in maintenance and terminal expenses. In these days, or indeed in any other days, a possible saving of 25 per cent. in any department of industry is sufficient amply to justify a most careful consideration.

PLATE SIXTEEN: FACTORS AFFECTING MODERN RAILROADING.

It is beyond the scope of this address, and it would weary you mercilessly, for me to attempt close analysis of other factors that have affected railroad operating performance during the ten years we have been considering. Volumes have been written on the subject, and volumes remain still to be written. Consistently it has been our purpose tonight to concentrate attention upon the locomotive and its part upon the railroads' battlefield.


THE STEAM LOCOMOTIVE IN AMERICA'S RAILROAD PROGRESS
FACTORS AFFECTING MODERN RAILROAD OPERATING PERFORMANCE
10 YEARS' PROGRESS: 1920-1929
1- LONGER ENGINE RUNS
2- GREATER POWER
3- HIGHER SPEED
4- BETTER MAINTENANCE
5- LONGER TRAINS
6- BETTER LOADING
7- QUICKER TURN-AROUND
8- BETTER ROADBEDS
9- IMPROVED TRAIN DISPATCHING
10- MORE PASSENGER TRACKS
11- MORE AND LONGER PASSING TRACKS
12- MORE MODERN SIGNAL EQUIPMENT
13- AUTOMATIC TRAIN CONTROL
14- COMBINATION FREIGHT AND PASSENGER LOCOMOTIVES
15- RAILROAD CONSOLIDATIONS
16- ELECTRIFICATION ADDITIONS
17- GROWING COMPETITION BY OTHER FORMS OF TRANSPORTATION
18- POOLING OF LOCOMOTIVES
19- REDUCTIONS IN FREIGHT TRAFFIC DUE TO ELIMINATION OF WASTE
20- THE URGE FOR ECONOMIES BY THE RAILROADS
21- CONCENTRATION IN DISTRIBUTION, THROUGH TERMINAL WAREHOUSE FACILITIES
22- BETTER COOPERATION BETWEEN RAILROADS
23- THE WORK OF THE CAR SERVICE DIVISION IN AMERICAN RAILWAY ASSOCIATION
24- THE WORK OF THE REGIONAL ADVISORY BOARDS THROUGHOUT THE UNITED STATES
25- FEWER COLLISIONS AND LESS DERAILMENTS
26- PUBLIC DEMAND FOR MODERN SERVICE
27- DIESEL-ELECTRIC DEVELOPMENT
28- REVAMPING PRESENT EQUIPMENT
29- "EGGS TO A HEN"
CYRUS FOGG BRACKETT LECTURE
PRINCETON UNIVERSITY
APRIL 14, 1931
PLATE 16
AMERICAN LOCOMOTIVE COMPANY
NEW YORK

Out of the myriad factors—physical, political and economic—that have affected and are affecting the destiny of railroading, I have selected some which are outstanding and are related directly or indirectly to locomotive utilization. There are twenty-nine of these and they are tabulated in this concluding chart. I wish time remained to discuss each with you, because of the humanly interesting ramifications so many of them have in our everyday life. Suffice it to explain one, which by coincidence only is the last in the list, and would be an enigma to you. I refer to "Eggs to a Hen."

"Eggs to a Hen" is that informal reference which dignifies a discussion indulged in by some members of the railroad fraternity. Its substance is a mild controversy in respect to the relationship between longer engine runs and the probable life of the motive power so operated. You will find divergence of opinion expressed by railroad managements. Some rail executives incline to the view that there are just so many miles of life in a locomotive—just so many "Eggs to a Hen"! Other executives take an altogether different view and are convinced that locomotive life will not be appreciably shortened by longer engine runs provided adequate maintenance is given. In any event let you and me not forget that in the final analysis the economic factor which determines the useful life of a locomotive, is obsolescence.

The other factors listed are self-explanatory.

And now we are done, in this analysis of ten-years' progress of a distinguished American institution—our railroad transportation system.

Together we have seen the obstacles which railroad management is surmounting in the preservation and constant improvement of a service essential to the continuance of our country. We have seen the contribution which the steam locomotive is making on this field of arms. We have seen that the doorway leading to future possibilities for further contribution is wide open. We have seen that at least half of the serviceable motive power owned by the carriers is of an age which points clearly to opportunity for railroad management to secure progressively greater improvements in the future. We have cited specific examples of the economics involved when older motive power is replaced by modern locomotives designed to meet the given conditions. We have seen that the expense of maintenance of motive power can be reduced through replacement by new units. We have seen a finger pointing to the future which suggests that the elements of transition and flux in the transportation situation in this country may be expected to be crystallized at a not far distant date—when the ultimate criterion of survival will be the economics involved. We have seen that the same finger points to a future in which the emphasis for rail transportation

will probably be upon the long haul and the expedited movement of freight, and upon the transport of passengers with an increasing measure of comfort and speed, combined with safety. Again, we have seen that this finger points to a future where the locomotive designer and builder will continue to be an all-important factor in the solution of the technical problems affecting motive power. As in the past so in the future, this technical experience with its background of research, invention and resorcefulness may be expected to continue its unrelaxed efforts towards greater efficiency, whether to be secured through super-pressures in steam practice or in refinement of internal combusion power far beyond anything that commercially has been developed to date.

With such a vista for future opportunity in important public service, you can realize how intriguing is the problem presented to the locomotive industry. Its responsibility towards transportation is in reality a responsibility to the country at large; not only because transportation is essential to the continuance of the nation's welfare, but because sustained integrity of values in ownership of railroad securities touches the safe deposit box of the American citizen. The locomotive industry confidently meets the challenge of its responsibilities and its opportunities—upon the railroads' battlefield!

It has been a great pleasure to meet with you tonight under the auspices of this great Institute. The subject which we have discussed together has broad significance in the social adjustment of America's future. As my closing comment, let me remind you that the railroads' battle must inevitably be waged upon the field of economics in transportation. Regulation and legislation only ameliorate or accent this contest to the extent that the regulation or legislation may be wise or otherwise.

Today a great authority says that the only act that a railroad may inaugurate of its own initiative, is the payment of a cash dividend. Gentlemen, I have a great respect for a cash dividend—a profound respect. As I watch them grow scarcer these days, my respect grows even more profound, but I insist that the main thesis is the free play of economics in transportation and that regulation and legislation are merely corollaries of this main thesis.

The decade which together we have examined, evidences a splendid development in the reduction of operating costs and represents an achievement of progressively improved efficiencies, all secured within the narrowing bounds of existing regulation. As the bounds become tighter, and who can believe that the tendency is otherwise, the struggle for great efficiency in transportation becomes more difficult. With some 80 per cent. of railroad prime movers over ten years of age, we have in their replacement, a powerful ally at hand capable of securing still greater economies, as yet unused. I predict that the coming decade will witness the modern locomotive advanced to the firing line, and by its aid the railroads will again move forward along their entire battle front.

Gentlemen: It occurred to me you will be interested to see a brief but considerably spectacular composite *motion picture* of high speed passenger service, where the *driving power* of the modern locomotive is shown up to the eye.

Through the courtesy of old and close friends of American Locomotive Company, namely the *New York Central Lines* I am enabled now to show you this film. It will need no explanation.

THE EXTENSION OF PASCHEN'S LAW TO INCLUDE THE ELECTRODELESS GLOW DISCHARGE.

BY

OTTO STUHLMAN, JR., Ph.D.,

The University of North Carolina.

INTRODUCTION.

If a difference of potential is established between two electrodes in a gas, the gas behaves as an insulator until the potential exceeds a critical value indicated by a breaking down of the insulating properties of the gas. This initial critical state is indicated by the appearance of a silent glow or "corona" discharge, which with increased potential changes in appearance to a "brush" discharge and then at higher potentials to a spark discharge.

Before the appearance of Toepler's paper in 1907 [1] no distinction was made between the phenomena accompanying the initial or critical potential at which the glow discharge sets in and the appearance of the disruptive discharge, or final sparking potential. For small spark gaps, however, the glow and brush discharge potentials overlap the sparking potentials so much that glow and sparking potentials become identical.[2]

The potential at which the glow discharge sets in is independent of the resistance of the circuit while the sparking potential, if differing from the critical potential at which glow discharge sets in, is dependent on the resistance of the circuit.[3] For fixed distances between electrodes the initial or critical discharge potential changes with the pressure of the gas. At high pressures the potential is large, it diminishes with pressure and reaches a minimum V_c for a certain critical value P_c of the pressure. If further reductions in pressure are made, the potential rises very rapidly and attains very high values at very low pressures.

The first quantitative analysis of the phenomenon was made by W. de la Rue and Müller,[4] who showed that the potential depends on the quantity of gas, at constant tempera-

ture, between parallel electrodes. Paschen [5] extended these observations, especially in relation to spherical electrodes and found that his detailed study led him to the conclusion that for all values of pressure down to a limiting critical value (P_c), the minimum potential necessary to excite a discharge is proportional to the product of the distance between the electrodes and the pressure of the gas. This relation has since then been referred to in the literature as Paschen's law.[2, 6]

Bouty [7] extended the work to the discharge in a gas when plane parallel electrodes were placed, in the form of condenser plates on the outside of the plane parallel sides of a cylindrical glass vessel. From the observed potential, at which the sudden glow in the gas appeared, as a function of pressure he obtained relations between pressure and potential similar to those found by Paschen.

Using a different method of attack, Gutton, Mitra and Ylöstalö [8] have investigated gases excited to glow discharge by a high frequency electrical field when the gases were inclosed in tubes provided with inner or outer electrodes. The resulting potential-pressure relations were found to follow the Paschen law and also preserved the critical minimum values of potential V_c and pressure P_c at very low pressures.

From the early work of B. Davis,[9] on the theory of the electrodeless discharge, one might also infer the linear relation between the potential and pressure as observed by Paschen.

The existence of Paschen's law as applied to high frequency discharge in gases at low pressures may also be inferred from the work of several investigators: that of Kirchner,[10] who used high frequency continuous-wave discharges in hydrogen, oxygen, neon and air with internal electrodes; that of Huxley,[11] who studied the corona discharge in helium and neon. More recent work by Hayman [12] on the potentials required to start and maintain high frequency discharges in helium and neon in cylindrical tubes, with sliding external sleeve electrodes excited by continuous-wave radiation, also shows the characteristic linear relation between the potential and pressure. Subsequent work by Townsend and Nethercrot [13] shows slight departures from Paschen's linear law, especially at pressures below 0.6 mm.

M. L. Braun,[15] using a high frequency undamped and what purported to be a predominantly electro-magnetic field associated with a pan-cake coil radiator, found that the field strength in terms of the current I through the exciting coil, in the case of an electrodeless discharge in hydrogen, oxygen and nitrogen followed very closely the relation I/p = constant. Characteristic departures from this linear relation are, however, apparent in his curves, especially near the critical minimum point. A further extension showing the minimum current necessary to maintain the glow discharge as a function of the frequency of the exciting field led him to the conclusion that the current in the coil was proportional to the pressure of the gas and to the wave-length of the exciting field. This is, in the first approximation, analogous to the results obtained by Hayman [12] for the potentials required to maintain the discharge in helium and neon using external sleeve electrodes.

Similar results for the electrodeless glow discharge in mercury were recently obtained by Smith, Lynch and Hilberry,[16] who succeeded, according to the writer's interpretation, in separating the magnetic effect ("bright discharge") usually referred to as the ring discharge [18] from the electrical effect ("dull discharge") without changing the form of the exciting coil. One would infer from this work that they simply changed their high frequency field from a predominantly magnetic to the electric form by decreasing the current through their short solenoid, which was used as an exciter of the electrodeless discharge. In obtaining their relations between critical potentials to initiate the discharge and frequency of the field they were apparently handicapped in getting more exact quantitative relations by the fact that "both types of discharge exist over the whole range of pressures." [16]

In view of the fact that a glow discharge was obtained by Braun [15] when his electrodeless bulb was introduced into what purported to be a predominant electromagnetic field associated with his pan-cake coil, one must conclude that the field associated with such a coil, when excited by high frequency but low current density continuous wave oscillations, is one of predominantly electrical rather than electro-magnetic

character, as MacKinnon [18] concluded from experiments with a similar coil.

Since a properly designed coil, in the form of a loosely wound inductance, produces along its axis a predominantly electrical field when excited by continuous wave, low current density oscillations, it was thought profitable to repeat the experiments of Braun [15] to lower gas pressures, lower frequencies and to extend the study to a more detailed investigation of the field strength necessary to excite and maintain the glow discharge in very pure gases at high and very low pressures.

To what extent these results can be incorporated into Paschen's law was the final objective sought.

TECHNIQUE.

The high frequency radiation was generated by a tuned-plate, tuned-grid, oscillatory circuit similar to that used by Braun.[15] A helical coil was used to generate the electrical field into which the electrodeless bulb was introduced. The range in frequency was from 1710 to 3333 k.c.

The coil, a loosely wound inductance, was 24 cm. long with 12 turns of 0.7 cm. copper wire. The coil had an internal diameter of 14 cm. Townsend and Donaldson [17] have shown that this type of solenoid develops, under high frequency excitation and low current, a predominant electric field. This conclusion has been verified by MacKinnon.[18]

The potential difference across the solenoid was obtained by a method suggested by Townsend and Donaldson,[17] in which two equal radio frequency condensers, each of capacity $2S$, and a hot wire milliameter are connected in series with the condensers at the opposite sides of the milliameter and the whole connected across the terminals of the solenoid. The P.D. is then given by $\sqrt{2}I/2\pi Sf$ where f is the frequency of the oscillating current as measured by a G. R. Co. precision wave-meter.

An electrodeless spherical pyrex glass bulb, 13 cm. in diameter, with the gas inlet at the top and outlet at the bottom, was placed in the center of the solenoid.

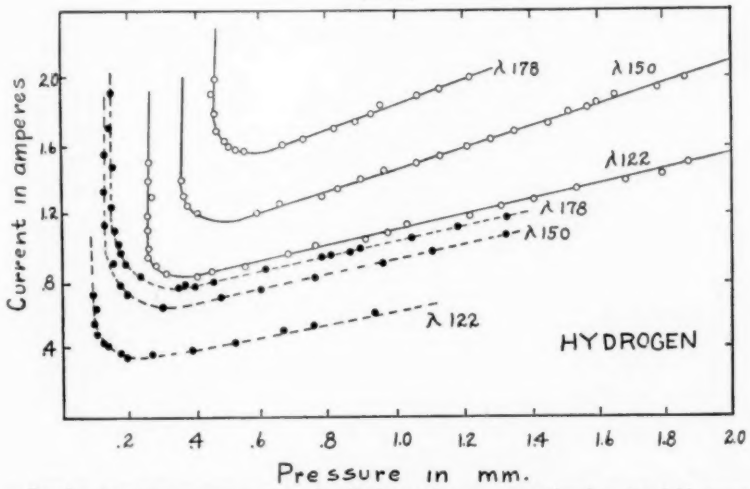
The hydrogen and nitrogen were derived from compressed steel tank storage, dried through sulphuric acid and soda lime towers. Oxygen was removed by pyrogallic acid wash-

ing while the mercury vapour from the pump was condensed with solid carbon dioxide. The bulb was heat treated, washed with the gas under examination, evacuated and then filled with the gas at a pressure of two atmospheres in order to saturate the walls of the bulb. The bulb was then exhausted to a high vacuum and the gas was slowly admitted through a capillary at the top.

For a predetermined frequency, the potential across the terminals of the solenoid was set, by adjusting the primary current of the filament transformer. As the pressure gradually rose by way of the capillary leak, the critical pressure was read on a McLeod gauge at the instant the glow discharge flashed. In view of the fact that the capillary leak was very slow it was found possible to follow this observation, the initiation of the glow discharge, by a reduction in the current and then by observing the minimum potential that would just sustain the glow discharge. The flashing and extinguishing of the glow was so critical that either observation was reproducible at will within the limits of sensitivity of the apparatus.

Figure 1 illustrates a typical set of observations showing the

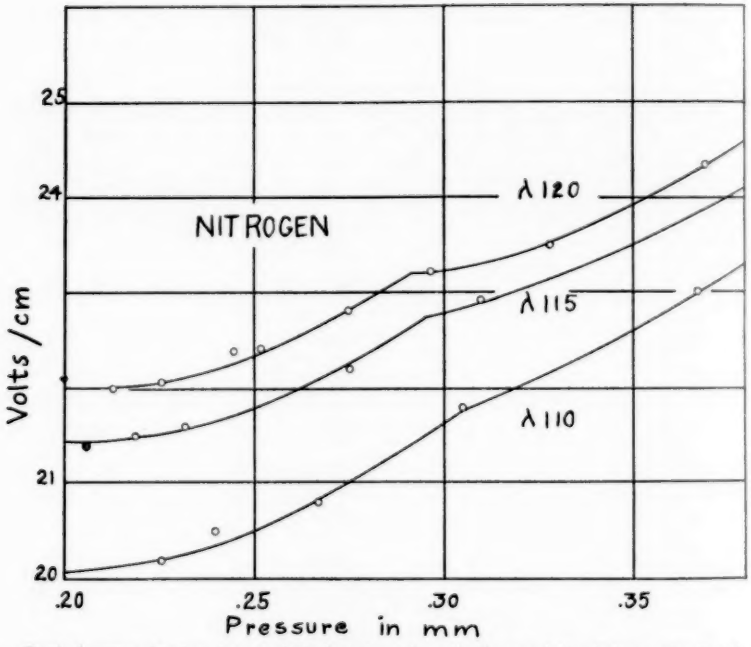
FIG. 1.



Results show the current in the solenoid, here taken as proportional to the field strength producing the high frequency field of wave-length λ in meters as a function of pressure in mm. of mercury. Solid lines represent conditions to initiate glow discharge, broken lines show conditions for minimum maintenance of glow discharge.

relation between the pressure of the gas at which the glow discharge sets in at various predetermined frequencies, and the current through the exciting solenoid. Here, as in Braun's work, the curves shift parallel to themselves with the knee of the curve moving to smaller current and pressure values as the wave-length of the exciting field decreases. At the higher pressures, the current necessary to initiate the glow discharge is, to a close approximation, a linear function of the pressure, although as Fig. 2 shows, characteristic detailed

FIG. 2.



Typical curves showing characteristic departures from the linear relation between the electrical field strength in volts/cm. and pressure of the gas in mm. of mercury for the initiation of the glow discharge, in pure nitrogen.

departures may be expected. For convenience of comparison with previous work, the current is plotted, instead of the field strength, since the current is directly observed while the value of the field strength is computed from this value and the known values of the capacitance across the coil and the frequency of the oscillating field.

The results show that as the knee of the curve is approached from higher pressures, the slope is constant and fulfils the demands of the Paschen relation. Near the knee of the curve the uniformity of the slope changes rapidly, passing into a rapidly changing one which rises nearly asymptotically with the axis of ordinates. The knee in the curve becomes more acute as the frequency of the field increases; this is also in agreement with Braun's [15] work.

Hence the results show a complete parallelism between the glow discharge in the gas, whether excited by a supposedly electromagnetic field associated with a pan-cake coil or an electrical high frequency field of low intensity, associated with a helical coil. Since the glow discharge is unquestionably attributable to the electric field as MacKinnon [18] has shown for damped wave excitation, one naturally concludes that both pan-cake coil and solenoid produce predominantly electrical fields under low current continuous wave excitation.

MINIMUM CURRENT TO MAINTAIN THE GLOW.

The second point at issue is the trend of the relation between field strength (E volts/cm.) and the pressure to maintain the glow discharge in a given gas at a predetermined frequency of the exciting electrical field.

In order to determine the minimum value of the field, just sufficient to maintain a discharge, the current was reduced in the solenoid until at a given pressure the glow suddenly extinguished.

The minimum maintaining potential was found in all cases for pressures above the critical pressure p_c to be less than the excitation potential except that at each increase in frequency the shift was both to a lower potential and to a lower pressure. Figure 1 also shows this parallelism between the two phenomena. While at low pressures the maintenance and initiation phenomena are running practically parallel, the departure from parallelism becomes more pronounced with increase in pressure after pressures of one milliameter or more are exceeded. Similar results were obtained by Townsend with neon excited by C. W. high frequency currents when the electrical terminals were attached in the form of sliding sleeves on the outside of his tubes. While Braun's

results for the maintenance of the glow discharge show no deviation at low pressures from the apparently linear relations, between current and pressure, his lower limits of pressure at .44 mm. prevented him from following the maintenance phenomena sufficiently further to obtain the sudden rise in the maintenance conditions comparable to those obtained in these observations.

No rigorous quantitative interpretation can yet be given to those results, since the values of the potential difference measurements, across the ends of the solenoid, were accurate to within only 2.5 per cent., whereas the pressure observations were obtainable, because of the continuous capillary leak, to within only 5 per cent. For comparison, however, the results of Townsend and Donaldson [17] may be cited. They found that in the case of neon, the minimum potential under which the discharge was maintained as compared to its initiation, was in the ratio of one to three, when an oscillating field of 83 m. wave-length was used.

From the data obtained by Braun [19] in this laboratory we find that the ratio of potentials, to initiate the glow discharge to that sufficient to maintain it, are of the same order of magnitude although slightly smaller, as can be seen from Table I.

TABLE I.

Ratio of Field Strength to Initiate and Maintain the Glow Discharge.

Gas.	Ratio.
Hydrogen	1.80
Oxygen	1.72
Nitrogen	2.01
Air	1.97

p at 0.5 mm. Hg, $\lambda = 120$ m.

Since critical initiation and maintenance potentials are, as Townsend and Donaldson [17] early found, exceptionally sensitive to the *slightest* traces of impurities in the gases, it was found that the above results can be taken only as representative values, because these gases were not spectroscopically pure, nor completely free from residual mercury vapour. In the case of *pure* hydrogen we found that a single group of observations was readily reproducible to an accuracy of 2.5 per cent., yet in subsequent observations on the same gas, treated for impurities in a slightly different manner,

results were not comparable with previous data to within about 10 per cent., thus again emphasizing the exceptional sensitivity of this type of discharge to the slightest traces of foreign gases. For this reason it is assumed that unless exceptional purity of gases was obtained, results published to date can have only a qualitative rather than a quantitative value.

With this reservation in mind we might compute the expected ratio of initiating to maintenance potential for air from the observed values for nitrogen and oxygen. Assuming air to be composed of 78 per cent. nitrogen and 21 per cent. oxygen by volume, we computed the above critical ratio to be 1.92 as compared with the observed value of 1.97, using the same pressure and frequency as cited in Table I. This is in better agreement than might be expected under the circumstances because of known impurities in the gases.

Since at higher pressures maintenance and initiation potentials are not strictly running parallel with increase in pressure, but change in slope at pressures greater than one milliameter, it should follow that the above critical ratios are dependent on both pressure and frequency of the exciting field. Figure 1 shows that they are strictly speaking not constant at all frequencies of excitation. The variation in the case of very pure hydrogen is from 2.5 to 1 for the longer wave-lengths, to 1.8 to 1 for the shorter wave-lengths.

CONCLUSIONS.

The discussion shows that the same critical form of the electrodeless glow discharge can exist at low pressures whether excited in a tube with loose external sleeve electrodes or completely free from electrodes, provided the exciting field is predominantly electrical. For pressures in excess of the critical pressure characteristic of the gas, the results show that in general Paschen's law can be extended to include the glow discharge, as excited by a high frequency electrical field under both initiating and maintenance conditions. For pressures less than the critical pressure both initiating and maintenance conditions run parallel and the field strength necessary to achieve these results increases very rapidly to very high values.

The ratio of field strengths to initiate and maintain the glow discharge for a given pressure and frequency of excitation are constant and characteristic of the gas, provided the field strength is not sufficiently great to produce in the gas its next higher excitation stage usually referred to as the "ring discharge," subject to the conditions that the size, shape and material of the container is the same and that the gas is at least spectroscopically pure.

The results possess theoretical significance in so far as these point to the conclusion that a pan-cake coil, contrary to expectations, will if excited by small currents but high frequency oscillations maintain a predominant electrical field at its center.

I take pleasure in acknowledging the assistance of H. H. zurBurg (Fellow in Physics) in taking the many painstaking observations.

CHAPEL HILL, N. C.,
October, 1931.

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A TWO-DIMENSIONAL ANALYSIS OF THE DISCRIMINATION OF DIFFERENCES IN THE FREQUENCY OF VIBRATIONS BY MEANS OF THE SENSE OF TOUCH.*

BY

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I.

THE BACKGROUND.

A. Sensations of Vibration.

The best introduction to a study of vibration sensations is probably Katz' "Der Aufbau der Tastwelt" (Leipzig, 1925), pp. 187–237. In a note on page 191 of that interesting work he points out that the possibility of using the tactile perception of vibrations as an aid to hearing, as a substitute for it, or as a means for the education of the deaf, was appreciated at an early date. A number of instances have been collected and published in Schumann's "Blättern für Taubstummenbildung." The earliest seems to have been Ammann's "Dissertatio de Loquela," published in Amsterdam in 1700. The principle was further developed by Georg Raphel in 1718 and by Perreire and Deschamps in 1779. Katz also quotes a passage from Rousseau's "Emile" describing the tactile sensations obtained from touching a vibrating violoncello and suggesting that such sensations might be of great service in teaching speech to the deaf.

How highly the ability to utilize such sensations may be developed is seen in Helen Keller, who claims to be able to enjoy the music of a concert, if her fingers can but touch the diaphragm of a radio ear phone, and in Sutermeister. The

* Being portions of a thesis submitted in partial fulfilment of requirements for the degree Doctor of Philosophy in Northwestern University. The work was undertaken at the suggestion of Professor Robert H. Gault and was carried on under his general direction. The author is indebted to Bell Telephone Laboratories and to the Western Electric Co. (Chicago) for the loan of oscillators; and to Professor V. O. Knudsen for the loan of certain other apparatus as well as for many valuable suggestions.

latter can enjoy concerts by means of the vibratory sensations received not through his fingers but from resonance within the chest cavity.

Johannes Müller and E. H. Weber both gave some attention to the sensations derived from vibratory stimuli. Weber's insight into the phylogenetic relations of the vibration sensations and hearing was acute—astonishingly so, when we recall that he wrote at least thirteen years before "The Origin of Species" made evolution a fundamental scientific dogma:

> Dadurch, dass sehr schnell aufeinanderfolgende auf die Tastorgane geschehende Stösse zu einer Empfindung zusammenfliessen, die Zeitraume aber, in welchem sich die Stösse folgen, die Empfindung abändern, haben wir einen Uebergang vom Tasten zum Hören. Wir fühlen die Erzitterungen als ein Beben die wir mit dem Gehörorgane als einen Ton wahrnehmen, und dieses Beben ist der mannicfaltigsten Modificationen fähig.[1]

In 1852 Valentin published the results of a study of tactile sensations derived from rotating wheels, vibrating monochords, and "tönende Zungenpfeifen."[2] His findings were utilized by Vierordt in 1868[3] to call in question the values then accepted for the duration of the shortest possible touch sensation. In 1869 von Wittich published some studies upon vibration sensations aroused by tuning forks.[4]

In 1889 Rumpf described a loss of vibratory sensitivity in connection with a case of syringomyelia.[5] This led Schwaner in the following year to offer a dissertation at the University of Marburg on "Die Prüfung der Haut-Sensibilität vermittels Stimmgabeln bei Gesunden und Kranken." Treitel in 1897 and Rydell and Seiffer in 1903 suggested the name Pallästhesie for vibratory sensitivity.

The clinical significance of Pallästhesie consists in the fact that it is apparently a distinct unit. It may be lost while other sensitivities of the skin and deeper tissues remain unimpaired; or it may persist when some of the others are lost. It is therefore a valuable means for the differential diagnosis of various peripheral and central nerve lesions.

The clinical possibilities attracted a large number of investigators. The best survey of studies from this point of view is probably that by Frank in 1921.[6] Another interesting survey, seven years later and with especial attention to the

writings of American neurologists, is to be found in Pearson's "The Effect of Age on Vibratory Sensibility." [7]

A very different approach to the matter was that of von Frey in 1914.[8] The study is an important one and deserves more general and closer attention than it seems to have received. Head, Frank, and a number of others believe the vibration sensations to be part of the "deep Sensitivity." Von Frey, however, would have them strictly cutaneous in location and merely peculiar forms of the pressure sense.

Katz, to whom we have already referred, holds that there is a distinct and separate vibration *sense*. He brings forward a number of ingenious arguments in support of his view. Fortunately there is no need to consider them in connection with our present undertaking.

The possibility of using vibration sensations in the instruction of the deaf, as we have seen, was very early appreciated. In recent years Professor Gault of Northwestern University has attracted considerable attention to this. His numerous writings and those of his students show conclusively that, when vibration stimulations are combined with visual (lip reading), a marked improvement results. This result, however, is only a gross affair. For any proper understanding of the significance of vibration sensations, this finding must supply the basis for a number of subsidiary problems. One such problem is undertaken in the present investigation.

B. Tactile Discrimination of Frequencies.

Although the tactile experience of vibrations has attracted considerable attention, and though the clinical importance of it has long been manifest, there have been astonishingly few studies of discrimination. Most investigators have occupied themselves with determining thresholds for stimulation, latency periods, or the frequency at which the separate impulses blend or fuse into a single sensation.

The first to attack the problem of frequency discrimination, so far as I have been able to ascertain, was Dunlap in 1911.[9] He employed a number of tuning forks with especially constructed bases. He would place a vibrating fork upon a subject's hand. He reported discriminations, by his most successful subjects, of differences as small as 5 per cent. In a

later publication he described the tactile perception of beats and difference tones.[10]

Dunlap's work seemed open to two criticisms. In the first place, there was no attempt to control the amplitude of the vibrations. Indeed there was probably no possibility of controlling it with such crude instruments as tuning forks. In the second place it seemed doubtful, in spite of the solemn affirmations of his subjects, that hearing was completely eliminated.

The next important investigation was that by Knudsen in 1928.[11] Here an expert physicist, using a vacuum tube oscillator as a source for the vibrations, devised and arranged instruments to permit the separate variation, control, and measurement of both amplitude and frequency. The present investigation deals with only one of the many interesting and important points covered in Knudsen's study. It differs from the corresponding portion in Kundsen's work only in that the subjects were highly practiced and that the procedure was somewhat more in accord with the standards of psychophysics. The result, as would be expected, is a finer discrimination than Knudsen obtained. His results ran from 8 per cent. at 256 d.v.'s (in his own case) to 35 per cent. at 512 d.v.'s (in the case of his assistant).

In 1930 Dr. Alo Kampik published a number of interesting studies of the vibration sensation. He found that his subjects generally could distinguish noises from musical tones. His best subject, with his hand on the sounding board of a piano, could discriminate half tones in the range from E to g'.[12]

This is certainly interesting and indicates a much finer discrimination than one would suppose possible after reading Knudsen. There is an obvious criticism, however, that here again there is no attention to the matter of amplitude.

II.

STATEMENT OF THE PROBLEM.

How minute differences in the frequency of vibrations can be discriminated by the sense of touch? This is certainly a reasonable question and it is the one with which the present investigation is concerned.

Earlier studies had indicated the probability of discriminating 10 per cent. intervals. Dunlap had claimed 5 per cent.

Kampik claimed half tones within a certain optimal range. On the other hand Helen Keller and Sutermeister claimed a sensitivity that implied a much finer discrimination than had been experimentally verified.

In all of these studies except Knudsen's insufficient attention had been given to the matter of amplitude. Knudsen's results were based on only two subjects and almost certainly fell far short of the maximum, because his subjects were not sufficiently practiced and because his procedure left much to be desired from the standpoint of psychophysics.

The present investigation was restricted to the region of 400 d.v.'s. The principal reason for choosing this was that Dunlap's original study had been in this region. 400 was chosen as a "standard" simply because it furnished an easy base for numerical computations. The "comparison" frequencies were 380, 420, and 410 d.v.'s. The subjects were all normal individuals.

Three different procedures were employed. What is believed to be an original and valuable feature of this study is the use of an "amplitude sieve" to furnish a "two-dimensional analysis."

III.

THE APPARATUS.

The apparatus employed was essentially that described by Professor Knudsen in the article to which reference has already been made. It is shown diagrammatically in Fig. 1. As his description is very clear and detailed, only the briefest account is required here.

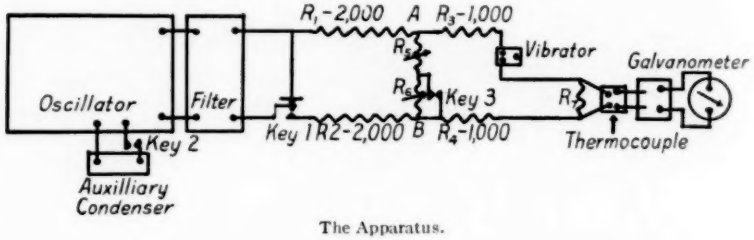
The vibrator, which transmitted the stimuli to the subject's finger, was constructed from the motor of a radio loud speaker. A smple system of levers amplified the vibration of the motor. The source of current was a vacuum tube oscillator.

The oscillator was adjusted to give the higher of the two frequencies studied at any one time. A supplementary condenser was so adjusted that, when it was thrown into the circuit, the increased capacity would diminish the frequency of the oscillations by the exact amount desired to give the lower frequency desired. Key 1 in the diagram connected the oscillator with the outlying circuit. When it alone was

pressed, the higher frequency was obtained. Key 2 connected the supplementary condenser with those in the oscillator. When both key 1 and key 2 were closed, the lower frequency was obtained.

The resistances R_3 and R_4 constitute essentially a potentiometer. When key 3 is in the shorting position, the whole potential drop from A to B supplies the e.m.f. to the vibrator. When key 3 is depressed, only a portion of that potential drop is utilized. By using two ordinary resistance boxes, it is possible to obtain any desired fraction of the total drop. The sum of the two resistances, of course, is kept constant. The third key, therefore, controls the amplitude of the oscillation. In one position it gives the maximum; in the other, whatever fraction of the maximum one may wish.

FIG. 1.



The Apparatus.

For measuring the amplitude of the vibrations an optical system was employed similar to that of Professor D. C. Miller's Phonodeik. By means of a tiny rotating mirror attached to the vibrating lever and reflecting a beam of light on to a graduated screen, the motion of the lever could be magnified nearly 2,000 fold.

To exclude hearing a sound barrier was introduced. A common buzzer was found sufficient. That hearing was effectually eliminated is proved (*a*) by the subjects' very emphatic verbal reports and (*b*) by the fact that they made numerous errors which hearing would certainly have prevented. The distribution of the errors, in the third place, is not such as would have occurred if there had been even the slightest hearing. The errors, as will be seen, increased in number as the amplitude of the higher frequency increased, i.e., as it might be expected to become more audible.

V.

PROCEDURE.

1. Subjects.

It is a pleasure to be able to acknowledge very deep obligations to the persons who gave so generously of their time and effort to serve as subjects. Miss DeVries (M. D. V.) was a teacher in the public schools of Los Angeles and a graduate student in the University of California in that city. Mr. Glynn Smith (G. S.) was an undergraduate at the same University. He had the misfortune to lose the sight of both eyes when he was about eight years old. He is exceptionally intelligent and an organist of superior ability. Miss Murray (M. M.) is a graduate student in Psychology at Northwestern University. Miss Kendal (E. R. K.) and Mr. Hennessy (F. H.) are undergraduate students at Northwestern. My wife (E. L. R.) assisted me both in Los Angeles and at Northwestern. With her help I was myself (W. H. R.) able to serve as subject in both places.

The work was very monotonous and fatiguing. The fine coöperation which I received from all those whom I have mentioned evinces an interest in science and a personal kindliness of which it would be difficult to speak too highly.

2. The Amplitude Sieve and Two-Dimensional Analysis.

The essence of the "amplitude sieve" and the two-dimensional analysis made possible by it is that a standard sensory stimulus, in this case a vibration impinging upon the skin of a finger, is compared with another of the same sort differing from it in both of two characteristics. One of these is kept constant and the other allowed to vary over a considerable range.

In this case a "standard" frequency of 400 d.v.'s and unchanging amplitude was compared with a frequency of 380, 420, and 410 d.v.'s with a variety of amplitudes ranging from 91 per cent. of the "standard" to 108 per cent. The design of the "sieve" for each interval studied is shown in Fig. 2. Each "cell" represents a frequency *and* amplitude to be compared with the "standard."

If good discrimination is obtained for all amplitudes of the comparison or variable frequency, we may conclude that we have a genuine discrimination of frequency. If, on the other

FIG. 2.

Schemes of Two-Dimensional Analysis.

Frequencies	Amplitudes 92%	94%	96%	98%	99%	101%	102%	104%	106%	108%
420										
410										
					"Standard" 400					
390										
380										

The diagram above requires correction for the frequency of 410 d.v.'s. The "sieve" actually employed for the study of that frequency difference is shown below.

	91%	93%	95%	97%	98%	99%	100%	101%	102%	103%
410										
							"Standard" 400			

hand, discrimination becomes confused at some point, we have the problem to explain the phenomenon in terms of the interaction of the two factors.

One of the possibilities considered was that discrimination would be found to be a function of the *energies* involved. In moving systems such as the one with which we are concerned, the energy is proportional to the square of both the amplitude and frequency.

$$\frac{E_2}{E_1} :: \frac{f_1^2 \cdot a_1^2}{f_2^2 \cdot a_2^2}, \text{ e.g., } \frac{1.05^2 \times 1.05^2}{1.00^2 \times 1.00^2} = 1.215 +.$$

Increasing both amplitude and frequency 5 per cent. would increase the energy more than 20 per cent.

From a purely arm-chair consideration of the simple mathematics depicted above, it seemed plausible that sub-liminal differences in the same sense (greater amplitudes with higher frequencies, lesser amplitudes with lower frequencies) would combine to produce discriminable units, and that differences in the opposite sense would mask each other.

The exact opposite was found. Higher frequencies were rendered less discriminable by greater amplitudes; and their discriminability was increased when they were given smaller amplitudes. In this, however, we are anticipating. The discussion of this interesting finding must be postponed until we come to treat the results of the experiment. It is mentioned here only to illustrate the application of the sieve and the method of two-dimensional analysis.

3. The Presentation of Stimuli.

The manner of presenting the stimuli for discrimination bore some resemblance to the well-known Seashore test for pitch discrimination. Two stimuli were presented in close succession. The subject was required to judge whether the second was faster or slower (some preferred to say higher or lower) than the first or equal to it. Each frequency-amplitude unit was presented fifty times, twenty-five times in the order $S - F$ and the same number of times in the order $F - S$.

If the procedure is compared with the Seashore test, however, the differences were perhaps more important than the resemblances. In the first place three judgments were permissible, as against two in the Seashore test. In the second, a number of the pairs of stimuli really were "equal." Thirdly, the subjects were informed of the interval or difference they were expected to discriminate and were practiced in the discrimination under investigation until success indicated some ability. Preliminary practice was found to be absolutely essential. For a considerable period subjects found it impossible to detect any differences in the stimuli. Gradually, however, criteria emerged, were tested, were accepted or rejected, and the serviceable ones were stabilized.

An attempt was made to standardize the practice. This was soon abandoned. No two subjects would attack the problem in the same way. Discussion, advice, and encourage-

ment or reproof had to be adapted to each personality. So it can only be said that practice was continued until it seemed to the experimenter that the subject stood a fair chance of making a satisfactory score. As soon as this probability appeared, the subject was given a "critical" or "record" series of stimuli. The judgments were recorded and analyzed.

It must be admitted that this procedure leaves much to be desired. A careful study of the emergence, fluctuation, and final stabilization of criteria would be interesting and might have important bearing upon research in other fields. It is to be hoped that other investigators will address themselves to this problem. So far as the present study is concerned, it must suffice to estimate the effect of this neglect upon the performance of the subjects. Obviously it can only have *diminished* the accuracy of discrimination. Subjects might very easily be insufficiently trained. It would be impossible to over-train them. The results may be critized, therefore, as indicating *less* than maximal discrimination; the opposite objection can scarcely be sustained.

4. Differences in Method.

(1) In the study of the interval 380–400, practice and the record series were with a single frequency-amplitude unit at a time. After practice the subject was given a series of fifty comparisons and four "equals." (Only the "standard" was ever repeated.) The "equals" were inserted only to render the series more difficult. The final score was based entirely upon the number of comparisons judged correctly. As soon as a test upon one unit was completed, the subject was practiced upon the next, and so on.

(2) In studying the interval 400–420 the subject was practiced upon all the units. In the test and the critical series the various units were presented in chance order. The stimulus sheet reproduced below shows the series used. The letters *S* and *F* stand obviously for Slow and Fast. They apply, it will be recalled, to the second of the two stimuli. The numbers 1 to 10 denote the amplitude of the variable or comparison frequency. No. 1 was the smallest, or weakest, and no. 10 the largest, or strongest. It will be seen that each series consists of twenty comparisons, equally divided between

I.

	1	2	3	4	5
1	S^1	S^2	S^8	S^5	F^7
2	S^{10}	=	F^2	F^4	=
3	=	F^{10}	F^3	F^8	S^7
4	S^9	F^9	=	S^6	F^5
5	F^1	S^3	S^4	=	F^6

II.

1	2	3	4	5
F^1	F^2	F^3	S^7	S^8
S^1	S^2	F^4	S^3	=
F^5	S^4	S^5	=	F^6
=	F^7	=	F^8	S^6
S^9	=	S^{10}	F^9	F^{10}

III.

1	2	3	4	5
F^4	F^7	=	F^8	F^9
S^1	=	S^{10}	S^2	F^{10}
=	S^9	F^5	F^6	S^6
S^4	S^8	S^7	=	S^3
F^1	F^2	F^3	S^2	=

IV.

	1	2	3	4	5
1	S^1	=	F^1	S^2	F^{10}
2	F^3	S^3	F^9	=	S^4
3	S^5	F^2	S^6	F^8	=
4	F^7	S^7	=	S^8	F^6
5	=	F^4	S^9	S^{10}	F^5

V.

1	2	3	4	5
F^2	S^{10}	S^8	F^1	F^3
F^4	F^7	=	S^6	S^2
S^9	=	S^5	F^5	F^6
=	S^7	F^8	S^3	=
F^9	F^{10}	S^4	=	S^1

VI.

1	2	3	4	5
S^7	F^6	F^8	S^6	=
S^8	F^7	=	F^9	S^5
=	S^4	S^3	F^3	F^4
F^1	=	F^2	S^2	S^1
S^9	F^{10}	S^{10}	=	F^5

PRESENTATION SERIES.

"slows" and "fasts," and five "equals." Twenty-five such series were given to each subject. This gave a total of fifty comparisons at each amplitude, five hundred comparisons in all, and one hundred twenty-five "equals."

(3) A third method, used only at the conclusion of the experiment, was a combination of the two just described. It had been found that discrimination of the interval 400–410 became very difficult when the higher frequency was given an amplitude 3 per cent. greater than that of the "standard." The curve suggested that a further increase of amplitude might result in a *reversal* of judgments. It was desired, however, to weight the possibilities as heavily as possible against this result.

Recourse was had, therefore, to a slight modification of the first method. The subject was given fifty pairs of stimuli at each single amplitude used. This, it will be noted later, favors a higher score. "Equal" judgments were prohibited; and subjects were forced to judge either Fast or Slow. The subjects, however, were given no preliminary practice. Nor

were they given any hints of the reversal that was expected. (This, of course, could not apply to myself when I acted as subject; but I could discern no significant difference in my own performance that could be attributed to my knowledge of the expected result.) And five record series were run off at a single sitting. There was thus no opportunity for the subjects to develop new criteria. Judgments had to be upon the basis of the standards that had served throughout the experiment.

4. The Methods Compared.

It is an advantage that similar problems were attacked by such dissimilar methods. The differing results indicate that discrimination is not a unitary ability or faculty. Any results obtained are valid only for the particular method of investigation employed. This would apply not only to vibrotactile problems but to discrimination studies in any sensory field.

Each method has its advantages and disadvantages. The first failed to show any greater difficulty in connection with one amplitude than with any of the others. Subjects could be practiced upon any single unit until practically perfect. There was the possibility, too, that very different criteria might be employed to distinguish the stimuli at the different amplitude levels.

The principal advantage of the method is that it is rapid and easy to operate. The experimenter need only throw a two-way switch or press certain keys in a required order. It also yields a much higher number of correct judgments. This has a certain emotional value for both the experimenter and the subjects.

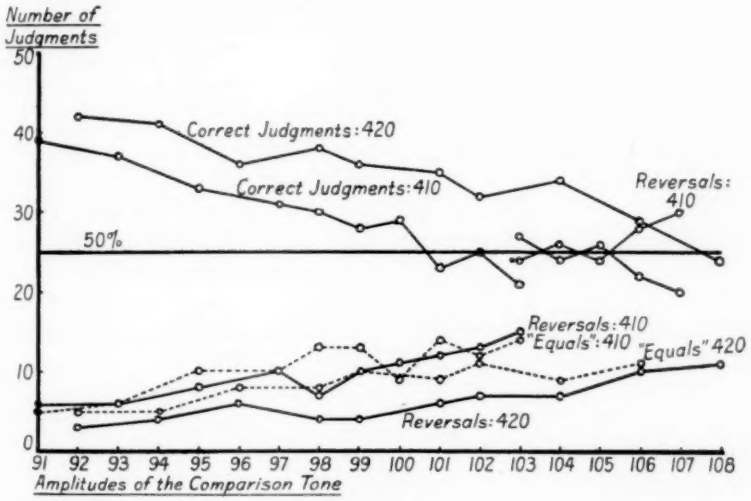
The second method did show clearly the greater difficulty of discrimination at the greater amplitudes of the comparison frequency. When these were varied, the task of discriminating Slows and Fasts became markedly more difficult. This is plainly visible in the table of results, the graph, and the individual record sheets. Instead of a single criterion for each frequency-amplitude unit, the subjects were compelled either (1) to fix upon some single criterion that could serve throughout the entire series, even when the amplitude relations were reversed (as between 1 and 10) or (2) to retain two or more

criteria in mind with which the stimulus could be successively compared.

The disadvantage of the method is that it is extremely tedious. The resistances across the circuit have to be very frequently altered. Even after the experimenter became fairly expert, it was not possible to give five more than five or six series in an hour. The strain upon both subject and experimenter is also very considerable.

On the whole, however, the second method must be considered not only superior but as the basic method for a two-dimensional analysis. It reveals the tendency of increased amplitude to mask the effect of higher frequencies. It is hard to see how any other method would show this.

The third method was simply an interesting variant upon the other two. It proved to be of value for the purpose for which it was employed.



DISCRIMINATIONS.

A frequency of 420 or 410 d.v.'s of various amplitudes compared with a "standard" of 400 d.v.'s and constant amplitude. Curves are for mean scores of five subjects.

* From this point the "standard" was progressively weakened and the procedure changed in the case of the 400–410 interval.

EXPLANATION OF THE GRAPH.

The graph should be studied in connection with the chart showing "The Schemes of Two-Dimensional Analysis."

Each cell of the chart represents a frequency-amplitude combination or "unit." Thus 420 — 92 per cent. means a frequency of 420 with an amplitude 92 per cent. of the "standard."

The "standard" for each series was a frequency of 400 with a fixed, or constant, amplitude.

The subject was given two stimuli for comparison. He was instructed to judge whether the second stimulus was faster or slower (some preferred to say higher or lower) than the first or equal to it. 20 per cent. of the comparisons *were* "equal." The various frequency-amplitude units were presented in chance order.

The curves show the number of correct judgments, of reversed judgments, and of "equal" judgments for each cell of the chart. The small circles clearly indicate the cells or frequency-amplitude units that were compared with the "standard."

In the case of the frequency 410 the procedure just described was modified after reaching the amplitude 103 per cent. This is clearly indicated by the break in the graph. The "third" method is fully described in the text. It may be repeated here that the "standard" was progressively weakened in order to give a greater *difference* in amplitudes, (2) "equal" judgments were eliminated, (3) instead of presenting the frequency-amplitude units in chance order, fifty judgments were made in rapid succession upon each single unit.

VI.

RESULTS.

A. The Interval 380-400.

The percentages of correct discriminations obtained for different amplitudes of a frequency of 380 d.v.'s compared with a "standard" of 400 d.v.'s and unchanging amplitude are shown in Table I.

It is evident that in this instance the only problem before the subjects was to keep their attention upon the stimuli. Discrimination throughout was practically perfect. The low scores of G. S. in the greater amplitudes was probably due to the fact that he began work at this end of the series. His subsequent improvement should apparently be attributed less to the easier nature of the discriminations required than to increasing practice and confidence.

TABLE I.
Interval 380–400.

Subjects.	Amplitudes.								
	92%.	94%.	96%.	98%.	100%.	102%.	104%.	106%.	108%.
E. L. R.....	98	100	92	98	98	—	100	96	100
M. D. V.....	—	92	96	98	98	100	94	94	96
W. H. R.....	98	96	96	94	100	100	98	96	100
G. S.....	100	100	100	98	98	98	90	88	88
Total.....	296	388	384	380	394	298	382	374	384
Means.....	99	97	96	95	98.5	99	95.5	93.5	96

EXPLANATION.

In the above table the amplitudes of the variable or "comparison" frequency are given as percentages of the "standard."

The scores indicate the per cent. of correct judgments.

As has already been noted, the method employed in connection with this interval gives no definite indication of the relative difficulty of discriminating the various frequency-amplitude units. The table does show, however, that subjects can fairly soon be trained to make discriminations of the type demanded with a very high degree of accuracy.

B. The Intervals 400-420 and 400-410.

The results of dealing with the intervals 400–420 and 400–410 by what has been described as the "second" method are shown in Tables II and III respectively and the results of the "third" method in connection with the interval 400–410 in Table IV. All these results are presented in visible form in the graph.

Three facts are at once apparent. The first is that, when the amplitude of the "standard" and the "comparison" frequencies are equal, a fair discrimination can be obtained of a difference in frequency as small as that between 400 and 410 d.v.'s — $2\frac{1}{2}$ per cent!

The second is that differences in frequency and differences in amplitude, when they are combined, operate antagonistically so far as discrimination is concerned. Diminishing the amplitude of the higher frequency increases the discriminability; increasing the amplitude diminishes the discriminability. If the amplitude be sufficiently increased, at least

TABLE II.
Interval 400–420.

Amplitudes.		Subjects.					Totals.	Means.
		E. R. K.	F. H.	M. M.	E. L. R.	W. H. R.		
92%	*C*	34	41	40	45	48	208	42
	R	7	2	4	2	2	17	3
	E	9	7	6	3	0	25	5
94%	*C*	34	46	36	44	47	207	41
	R	11	2	5	2	0	20	4
	E	5	2	9	4	3	23	5
96%	*C*	31	40	27	38	44	180	36
	R	11	5	9	5	2	32	6
	E	8	5	14	7	4	38	8
98%	*C*	33	46	32	33	45	189	38
	R	6	1	10	3	2	22	4
	E	11	3	8	14	3	39	8
99%	*C*	25	45	35	35	41	181	36
	R	10	0	5	5	1	21	4
	E	15	5	10	10	8	48	10
101%	*C*	31	37	31	29	46	174	35
	R	14	4	6	6	1	31	6
	E	5	9	13	15	3	45	9
102%	*C*	28	39	29	25	39	160	32
	R	12	2	8	12	2	34	7
	E	10	9	13	13	9	54	11
104%	*C*	31	37	31	30	42	171	34
	R	9	7	9	9	3	37	7
	E	10	6	10	11	5	42	8
106%	*C*	24	37	22	24	39	146	29
	R	17	7	10	13	2	50	10
	E	9	6	18	13	9	55	11
108%	*C*	17	22	26	25	32	122	24
	R	13	13	12	12	2	52	10
	E	20	15	12	13	16	76	15
Equals	*S*	32	25	23	26	21	127	25
	E	46	55	54	68	82	305	61
	F	47	45	48	31	22	193	39

EXPLANATION.

In the above table the amplitudes of the variable or "comparison" frequency are given as percentages of the "standard."

C denotes correct judgments, *R* reversed judgments, and *E* judgments of "equal."

In the judgment of equal or repeated stimuli *S* denotes judgments of Slow, *F* of Fast, and *E* the correct judgment of "equal."

TABLE III.
Interval 400–410.

Amplitudes.		Subjects.					Totals.	Means.
		E. R. K.	F. H.	M. M.	E. L. R.	W. H. R.		
91%	*C*	32	41	35	45	44	197	39
	R	16	4	6	2	1	29	6
	E	2	5	9	3	5	24	5
93%	*C*	34	33	30	47	43	187	37
	R	10	11	7	1	2	31	6
	E	6	6	13	2	5	32	6
95%	*C*	29	32	37	30	36	164	33
	R	11	8	5	7	7	38	8
	E	10	10	8	13	7	48	10
97%	*C*	26	38	27	30	33	154	31
	R	16	8	11	8	5	48	10
	E	8	4	12	12	12	48	10
98%	*C*	25	26	35	34	29	149	30
	R	12	12	9	2	1	36	7
	E	13	12	6	14	20	65	13
99%	*C*	26	25	24	27	36	138	28
	R	9	10	15	11	3	48	10
	E	15	15	11	12	11	64	13
100%	*C*	22	28	26	33	38	147	29
	R	18	15	10	9	5	57	11
	E	10	7	14	8	7	46	9
101%	*C*	24	25	18	25	25	117	23
	R	11	15	17	9	9	61	12
	E	15	10	15	16	16	72	14
102%	*C*	24	26	28	24	25	127	25
	R	16	14	13	12	8	63	13
	E	10	10	9	14	17	60	12
103%	*C*	18	21	24	23	21	107	21
	R	20	16	12	13	12	73	15
	E	12	13	14	14	17	70	14
Equals	*S*	27	28	27	33	34	158	32
	E	37	49	37	58	56	229	46
	F	61	48	61	34	35	238	48

EXPLANATION.

In the above table the amplitudes of the variable or "comparison" frequency are given as percentages of the "standard."

C denotes a correct judgment, *R* a reversed judgment, and *E* a judgment of "equal."

In the judgment of equal or repeated stimuli *S* denotes judgments of slow, *F* of fast, and *E* the correct judgment of "equal."

TABLE IV.
Interval 400–410.
(Third Method).

Amplitudes.	Subjects.					Totals.	Means.
	E. R. K.	F. H.	M. M.	E. L. R.	W. H. R.		
103% *C*	29	24	31	19	30	133	27
R	21	26	19	31	20	117	23
104% *C*	23	26	25	21	18	113	23
R	27	24	25	29	32	137	27
105% *C*	26	33	25	19	28	131	26
R	24	17	25	31	22	119	24
106% *C*	20	19	24	27	18	108	22
R	30	31	26	23	32	142	28
107% *C*	21	24	18	22	16	101	20
R	29	26	32	28	34	149	30

EXPLANATION.

In the above table the amplitudes of the variable or "comparison" frequency are given as percentages of the "standard." Unlike the procedure at other times, these ratios were obtained by diminishing the amplitude of the "standard."

C denotes correct judgments, *R* reversed judgments. The judgment of "equal" was prohibited and there were no equal or repeated stimulations.

in the case of a frequency difference as small as that between 400 and 410 d.v.'s, a preponderance of reversed judgments is obtained, i.e. the higher frequency is judged the lower.

The third point is that the discrimination of larger differences is, as one would expect, easier than of the smaller. The discrimination of the smaller differences, too, is sooner confused by increasing the amplitude of the higher frequency. Whereas a difference of 20 d.v.'s was readily discriminated until the amplitude of the higher frequency was 8 per cent. greater than the "standard," a difference of 10 d.v.'s was barely discriminable when the difference in amplitudes was in the neighborhood of 3 per cent.

The result of the "third method" is plainly apparent where the curve for the discrimination of 410 d.v.'s is broken at the amplitude of 103 per cent. Reference should be made to the table of results which the curve is drawn to illustrate. It will be seen that the initial improvement due to the differ-

ence in procedure would have been still more noticeable but for the very low score of a single subject (E. L. R.) Only one individual (M. M.) shows the uniform deterioration of discrimination that might be assumed to be "typical." The curve for the mean of the group of five, however, is remarkably uniform; and by the end of the fifth series every subject is safely below the 50 per cent. level. It is plain that a reversal of judgment was obtained simply by increasing the difference in amplitude between the comparison frequency and the "standard."

The discriminations reported should be viewed with reference to the frequency values of musical tones in this region. The following are taken from Dayton C. Miller's "The Science of Musical Sounds" (p. 48).

G	387
G♯	410
A	435

It is clear that 20 d.v.'s here represents a scale difference of a little more than a third of a tone. The interval of 10 d.v.'s would accordingly represent a little more than one sixth of a tone. Such a discrimination is, of course, greatly inferior to that of which the ear is capable under test conditions but may not be greatly inferior to the discrimination actually exercised by average uncritical listeners to music.

There is no reason to suppose that the results reported represent a maximum discrimination. Rather the contrary appears. The power to discriminate vibration frequencies tactually is certainly modified by practice. Persons who have any motive to concentrate for prolonged periods upon sensations of vibration may very well develop a much keener discrimination. The results obtained in this investigation tend to confirm the accounts of Helen Keller and Sutermeister —though they hardly need such confirmation.

The question as to the extent to which the antagonistic factors of frequency and amplitude can be dissociated is puzzling and is not answered in this study. The graph shows clearly that such dissociation is roughly proportional to the frequency difference. It would be interesting to plot the

curve of what we might call "confusion points" for various frequency and amplitude combinations. Is there a difference in frequencies so large that no ordinary manipulation of amplitudes can confuse the discrimination of it? Would further practice eliminate the confusion and the reversals found in the case of small differences? These are questions for further research.

It is difficult to assign any reason why the higher frequencies should be felt as relatively superficial or weak. I offer only a few conjectures as suggestions to others who may wish to investigate the problem. There seems to be an upper limit for vibration sensations—though it has not yet been fully determined. If vibration sensations disappear at this limit, it seems entirely reasonable that they should be felt as weaker the closer they approach it. But it must be borne in mind that the present study deals with only a single region, a narrow frequency band from 380 to 420 d.v.'s. We must not hastily assume that the higher and lower frequencies will have the same characteristics in other regions. The reason, I believe, must be sought in some feature of wave mechanics. The vibrator must produce undulatory deformations of the skin. To this the skin, of course, offers some resistance. I would expect a higher resistance to the more rapid undulations. Here, as in so many other problems, a close coöperation between physicists and psychologists is greatly to be desired.

VII.

ANCILLARY PHENOMENA.

In addition to the results which have been just now described, some additional phenomena were noted which deserve at least brief mention.

Among the most interesting were those in connection with the establishment of criteria. A subject would be practising upon a certain interval. No difference between the two stimuli could be discerned. Test series would yield only chance results. Suddenly the subject would exclaim, "I think I have it now." Tests might or might not prove the criterion reliable. Whence did it come? No one could say. Suddenly the two stimulations felt different. It seemed to emerge

suddenly and inexplicably from the intense concentration upon the stimuli.

It was, even at its best, subject to curious and often exasperating vagaries. It might function admirably for half of a critical series and then fail absolutely. It might even squarely reverse itself. On such occasions the subject would wail, "I've lost my criterion." This necessitated a period of further practice and the postponement of test or record series. Individuals differed greatly in this respect; and different situations or emotional attitudes also had characteristic effects. The most favorable attitude was one of close but not strained attention combined with a degree of placid contentment.

Practice tended to stabilize the criteria. Their discovery seemed to be facilitated by the descriptions and suggestions of the experimenter. It was found to be particularly important to confine the stimulation to the particular spot on the finger that might be yielding good results. The slightest changes of position or pressure were often disconcerting.

One of the most curious of the criteria was that of localization within the finger. It not infrequently happened that, one stimulus would be felt as affecting one side of the finger the other stimulus the opposite. Or more often, perhaps, one would be felt as superficial, on the surface of the skin, or close to the finger nail; the other would be felt as voluminous, filling the entire finger tip. Dr. Crane in a note to me states that in his researches he encountered similar localizations.

One phenomenon, that may have important theoretical consequences, I venture to call synesthesia. Once while working as subject in connection with another investigation, I noted that when I touched the vibrating mechanism I I seemed to *hear*. When I did not touch it, I did not hear. I am of the opinion that there was no possibility of physical conduction of auditory stimuli but that the hearing was a purely associative response. One subject seemed particularly prone to this and prove unsuitable either for this particular investigation or for another in which she was engaged. Professor Gault has reported similar phenomena. In one case the combination of visual (lip reading) and vibratory stimuli produced a most vivid impression of hearing. Careful tests, however, revealed no genuine hearing. In a certain drowsy

state, too, there were occasional vivid impressions of very definite sounds—words and sentences. When the results were analyzed, however, the judgments in such instances were no more frequently correct than when such impressions were utterly lacking.

These suggest that the usual experience of "hearing" is probably a complex into which many factors enter besides auditory stimuli in the strict sense. Almost everyone knows that a violinist can produce an illusion of hearing throughout a large audience by drawing his bow above the strings of his instrument but not in actual contact with any. We may have here another instance of *Gestalt* functioning. The possibility that a very high development of tactile vibration-sensitivity may serve as a more or less effective substitute for auditory sensitivity either wholly or partly lost is, of course, dubious; but it cannot be dismissed as utterly preposterous.

VIII.

DISCUSSION.

A. Frequency or Amplitude?

The usual procedure in studies of frequency discrimination (in the field of sound) is to maintain an equality of amplitude. The only factor varied is that of frequency. In the present investigation, indeed as almost its central feature, *both* frequency and amplitude are varied. Two questions are likely to arise. (1) Is such a procedure valid? (2) Are the results obtained genuine discriminations of frequency or of amplitude?

An account of the origin of the "amplitude sieve" and its use for "two-dimensional" analysis of discrimination may help us to deal with these questions. In an early stage of the investigation it was felt that the results were simply too good to be true. One subject discriminated a 5 per cent. difference with such readiness and certainty that I was led to suspect something wrong. The obvious possibility was that the two frequencies differed in amplitude and that the discriminations were based upon that difference rather than upon the frequency. No means were then available for the measurement of the amplitudes, although the construction of the oscillator permitted a very minute control. To test the

matter I adjusted the oscillator to give a comparison frequency that was felt as slightly but definitely weaker than the "standard." I set it again to give one that was similarly stronger. The difference between the two settings was divided into ten equal intervals. If the discrimination was a genuine frequency discrimination and independent of the amplitude, it should be perfect, or nearly so, at all ten settings. Because I thought of the frequency factor as being sifted or strained through this device, I christened it "the amplitude sieve."

The result confirmed my suspicions. At either extreme of the range of amplitudes the subject's discriminations were easy and sure. At certain amplitudes toward the middle, however, she became helplessly confused. Her verbal report confirmed the finding. The conclusion was certain that the discriminations were not uninfluenced by variations in amplitude. It would have been rash, however, to have concluded that they were based upon amplitude alone.

When it became possible to measure the amplitudes with some precision, the method of "two-dimensional" analysis naturally suggested itself. The results obtained by what has been called "the first method" were disappointing. The use of the "sieve" convinced me that I had a genuine discrimination of frequencies; but, as the score was practically perfect at all amplitudes, it seemed that no one of them presented any greater difficulty than the others. The "second method," however, yielded the striking results just described and graphically represented.

A casual glance at the graph might lead one to think that the discriminations obtained are not discriminations of frequency at all but of amplitude. If, however, attention is first given to the region of the graph at which the amplitude of the "comparison" frequency is shown as 100 per cent., i.e. *equal to the "standard,"* it is plain that a genuine frequency discrimination, in the strictest possible sense of the term, was obtained. The remainder of the graph indicates that, if the amplitude of the "comparison" frequency be decreased, it becomes more readily discriminable, while it becomes less discriminable if its amplitude be increased.

If we were dealing only with an amplitude discrimination, confusion would occur close to the point of objective equality,

i.e. in the vicinity of 100 per cent. on the graph. Actually 420 d.v.'s is not difficult to discriminate until its amplitude becomes all of 8 per cent. greater than the "standard." The frequency of 410 d.v.'s shows a similar confusion when its amplitude is 3 per cent. greater than the "standard." The proportion seems entirely reasonable.

There is, of course, the possibility that the calibration of the instruments and hence the calculation of the amplitudes is in error by a sufficient amount to destroy the force of the above argument. That can be determined only by other investigators. It should be noted, however, that the use of the "sieve" tends to minimize the significance of small errors. An error would be graphically represented only by a shift in the origin (the 100 per cent. point). The form of the curves would be unaffected and the antagonistic operation of frequency and amplitude would remain unassailed. A glance at the graph will show that in the case of 420 d.v.'s the error would have to exceed 8 per cent. and in the case of 410 d.v.'s 5 per cent. before it could be fairly charged that discrimination was based upon amplitude alone.

I would conclude that the question whether a given difference in frequency can be successfully discriminated or not, is not one that can be answered by a simple yes or no. Discrimination is a matter of degrees. It is also a function not of frequency alone but of frequency and amplitude in combination.

B. The Criteria of "Discrimination."

It is apparent that for a considerable portion of its length the curve for the correct judgments of the 400–410 interval lies very little above the 50 per cent. line. Can such a slight preponderance of correct over incorrect judgments be adequate ground for a claim that a real "discrimination" has been obtained?

It should be borne in mind that in any given comparison there were two possibilities of error but only one correct judgment. The subject was permitted to judge Slow, Fast, or Equal. In every series of 25 there were five for which "Equal" was the correct response. As the curve in question does remain for nearly all its length above the 50 per cent. line, it is plain that the correct judgments exceed *the sum* of the two

forms of error. The curve for the correct judgments should properly be compared not with the 50 per cent. line but with either of the two curves representing the errors—say with whichever may be the higher at any point.

It is tempting to try for some single index of the discriminability of each frequency-amplitude unit. The employment of *three* judgments makes this difficult. Three methods of overcoming the difficulty suggest themselves. (1) The "Equals" might be ignored. (2) They might be distributed in equal portions between the correct and the reversed judgments. (3) They might be distributed in the proportion already obtaining between the two. Any of these procedures would elevate the curve well above the 50 per cent. level.

I am of the opinion, however, that calculations of such a sort arrive at only meretricious conclusions. They give an appearance of high precision to measurements of entities that are highly unstable and elusive. I have therefore left the data and the curves in their present forms. They show that in the circumstances described a certain number of correct judgments were obtained, another number of reversed judgments, and still another number of "Equals."

C. Was Hearing Eliminated?

In view of the rather fine discriminations obtained, it is a fair question whether my subjects were not hearing. As evidence against this I offer the following considerations.

(1) The unanimous and emphatic declarations of all the subjects were to the effect that they could not hear the vibrations. The instrument made very little sound; and the barrier of noise seemed more than sufficient to obliterate it as a factor in judging.

(2) The number of errors far exceeded any that would have been possible, had the subjects been able to hear. A difference of ten d.v.'s in this region is very plain to the ear. None of the subjects was tone deaf.

(3) The errors, moreover, showed a consistency and a characteristic distribution that the least hearing would have rendered most improbable. In both the 400–410 and 400–420 intervals the errors became more numerous as the amplitude of the higher frequency increased—i.e. as it became *more*

audible, had it been anywhere near the threshold of hearing. The increase in the number of errors, too, as the interval was diminished is plainly due to the greater difficulty of the *tactile* discrimination, since neither interval presents the least difficulty for the ear.

D. Comparison with Knudsen's Results.

This study, made with Professor Knudsen's generous assistance and employing his apparatus, must obviously be compared with his—to which reference has repeatedly been made. It will be recalled that the finest discrimination reported by him was 8 per cent. in a single subject. In the present study $2\frac{1}{2}$ per cent. is claimed for a group of five. How should we account for the difference?

Two factors, I believe, are sufficient to explain the better performance of my subjects. The first, and doubtless the most important, is practice. The work occupied somewhat more than two months after the apparatus had been set up and tested. Subjects were trained for a week or two weeks before they were permitted to make record series. In the second place simple psychophysical methods and principles were employed. The number of comparisons was relatively large. For each interval about 500 comparisons were demanded. For the groups this yielded 1,800 and 2,500 comparisons respectively for each interval.

IX.

PROBLEMS FOR FURTHER STUDY.

1. The most obvious suggestion for further study is the application of the technique so far developed to other frequencies, e.g., to standards of 100, 200, 800, 1,200, 1,600, and 2,000 d.v.'s.

2. By choosing various amplitudes of the fixed frequency as "standard," the "sieve" could easily be extended into a third dimension.

3. The effect of various stimulating surfaces, sharp, blunt, or rounded, and of various dimensions ought to be investigated.

4. The effect of various degrees of pressure upon the vibrating element should be ascertained.

5. Fessard's [13] use of the oscillograph opens up interesting possibilities for the study of skin deformation or the damping of the vibratory elements through pressure.

6. Von Frey's experiments (1914) should be repeated and checked. The effect of stimulating various "spots" should be studied.

7. A very careful study, both "objective" and "introspective" should be made of the emergence, fluctuation, and final stabilization of criteria.

8. Individual differences would supply abundant material for interesting studies.

X.

SUMMARY.

The tactile perception of vibrations has attracted considerable attention among European physiologists and neurologists. From a clinical standpoint it has been found to be a highly reliable and significant means of diagnosing peripheral and central nerve lesions.

Of the tactile *discrimination* of vibration frequencies, however, there have been astonishingly few studies. Those of Dunlap, Knudsen, and Kampik practically exhaust the list. Of these only Knudsen's considers the question of amplitudes. His arrangement of apparatus makes possible the separate control and measurement of both amplitude and frequency. His procedure, however, was defective from the psychological point of view.

In this investigation Knudsen's arrangement of apparatus was employed; and the experimenter benefited by the kindly help of Professor Knudsen's assistant, Mr. Delsasso.

An original feature of the present study is the "amplitude sieve" and the "two-dimensional analysis" which it makes possible. A "standard" frequency of 400 d.v.'s and unchanging amplitude was compared with frequencies of 380, 420, and 410 d.v.'s with amplitudes in each case ranging from about 92 per cent. of the "standard" to about 108 per cent.

For the interval 400–380 subjects were practiced and tested upon each frequency-amplitude unit separately. This yielded practically perfect scores and failed to reveal any difference in the difficulty of discriminating the various units.

In the case of the intervals 400–420 and 400–410, the various units were presented in chance order. The results demonstrated the value of the "sieve," "two-dimensional" analysis, and the method of presentation employed. It was found that, with reference to discrimination, differences of frequency and amplitude operate antagonistically. A higher frequency is readily discriminated from a lower, so long as the higher has a lesser amplitude. As its amplitude is increased, discrimination becomes more and more difficult. This effect is more pronounced in connection with smaller frequency differences than with larger. By sufficiently increasing the difference between the amplitudes in the case of the 400–410 interval, it was found possible to obtain a preponderance of reversed judgments.

It is claimed that discrimination was obtained for differences of frequency as small as $2\frac{1}{2}$ per cent. of a "standard" of 400 d.v.'s.

There is nothing to indicate that this is a maximum.

A number of problems are suggested for further research.

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Definitions for Strained Tomato Products Proposed. (U. S. Department of Agriculture Press Service.) The Food Standards Committee has proposed the following new definitions and standards for strained tomato products:

Strained Tomato is the unconcentrated product consisting of the entire pulp and liquid, exclusive of skins, seeds and cores, obtained from ripe tomatoes with or without the application of heat; and with or without the addition of salt. It is packed in hermetically sealed containers and processed by heat.

Tomato Puree, Tomato Pulp, is the product resulting from the concentration of the entire fleshy and liquid portions of ripe tomatoes, exclusive of skins, seeds and cores, with or without the addition of salt. The finished product contains not less than 8.37 per cent. of tomato solids.

Tomato Sauce, "Salsa," is the product resulting from the concentration of the entire fleshy and liquid portions of ripe tomatoes, exclusive of skins, seeds and cores, with or without the addition of salt, and with or without the addition of basil and/or other seasoning. The finished product contains not less than 16 per cent. of tomato solids.

Tomato Paste, "Pasta," is the product resulting from the concentration of the entire fleshy and liquid portions of ripe tomatoes, exclusive of skins, seeds and cores, with or without the addition of salt, and with or without the addition of basil and/or other seasoning. The finished product contains not less than 22.0 per cent. of tomato solids.

Heavy Tomato Paste, Concentrated Tomato Paste, "Concentrato," is tomato paste containing not less than 35.0 per cent. of tomato solids.

(Concentrated tomato products are commonly packed in hermetically sealed containers and processed by heat.)

The Committee invites criticisms and suggestions on the proposed definitions from food officials, consumers, and the trade. Communications should be addressed to A. S. Mitchell, Secretary, Food Standards Committee, Federal Food and Drug Administration, Washington, D. C.

R.

THE DIELECTRIC CONSTANT AND POWER FACTOR OF ROSIN OIL AND ETHYL ABIETATE.*

BY

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Bell Telephone Laboratories.

It was suggested by Debye [1] that the large changes of dielectric constant and absorption which had been observed in the region of very short electric waves for substances such as water and alcohol were due to the existence of a permanent electric moment in the molecules of these substances, which had a time of relaxation such that they would show an absorption in this frequency region. This was confirmed experimentally for glycerine and a series of alcohols by Mizushima.[2] Later work has shown the same behavior in typical insulating substances [3] such as rosin, rosin oils, castor oil and insulating oils and also for mixtures of polar substances with viscous non-polar oils.[4] Most of these studies have indicated the qualitative correctness of the Debye theory.

The first measurements of Mizushima and others were made at high radio frequencies and while the explanation of the anomalous dispersion of dielectric constant and power-factor by means of the orientation of polar molecules was generally accepted as accounting for the loss at radio frequencies it was believed that it could not explain losses at low frequencies.[5] Kitchin and Müller's paper, however,

* Presented at the meeting of the Committee on Insulation of the National Research Council at Washington, D. C., November 8, 1930.

[1] P. Debye, *Verh. deut. phys. Ges.*, **15**, 777 (1913).

[2] S. Mizushima, *Bull. Chem. Soc. Japan*, **1**, 47, 83, 115, 143, 163 (1926).

[3] D. W. Kitchin and H. Müller, *Phys. Rev.*, **32**, 979 (1928).
L. S. Ornstein and G. Willemense, *Zeit. f. Tech. Phys.*, **11**, 345 (1930).
H. H. Race, *Phys. Rev.*, **37**, 430 (1931).
E. Kirch and W. Riebel, *Arch. f. Elektrot.*, **24**, 355, 553 (1930).

[4] R. Goldammar and H. Sack, *Phys. Zeit.*, **31**, 224 (1930).
J. H. L. Johnstone and J. W. Williams, *Phys. Rev.*, **34**, 1483 (1929).

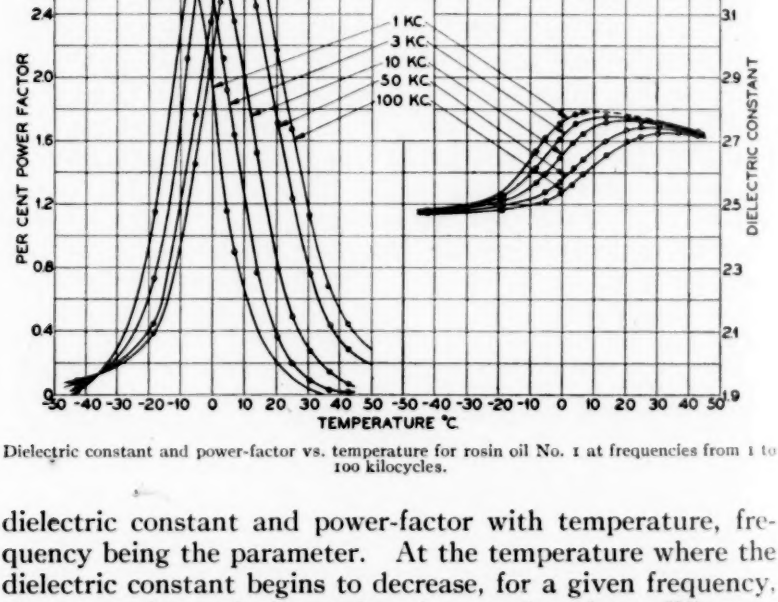
[5] F. Hamburger, Jr., *Phys. Rev.*, **35**, 1119 (1930).
A. Gemant, "Electrophysik der Isolierstoffe," Springer (1930).

showed that the same behavior was observed for rosin at 60 cycles as at 10^7 cycles, being merely displaced to a lower temperature as predicted by the Debye theory. Gemant, however, interprets Kitchin's data as an example of the Wagner effect and not as due to dipoles. The same behavior has been shown for an insulating oil by Race.

The work reported here extends from power frequencies up to radio frequencies and shows that essentially the same behavior is observed over the entire range. The materials studied were typical insulating substances derived from rosin, being two samples of rosin oil and ethyl abietate. The measuring equipment has been described elsewhere.[6]

The data are shown in a series of curves and require very little explanation. Figures 1, 2 and 3 show the variation of

FIG. 1.



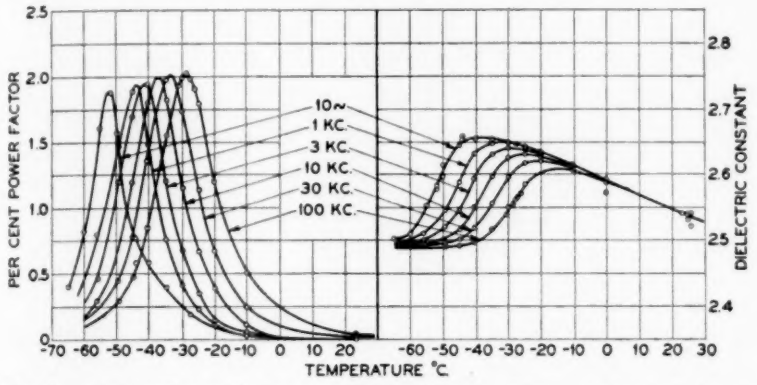
Dielectric constant and power-factor vs. temperature for rosin oil No. 1 at frequencies from 1 to 100 kilocycles.

dielectric constant and power-factor with temperature, frequency being the parameter. At the temperature where the dielectric constant begins to decrease, for a given frequency, the power-factor is increasing due to the phase difference

[6] S. O. Morgan and H. H. Lowry, *J. Phys. Chem.*, **34**, 2385 (1930).

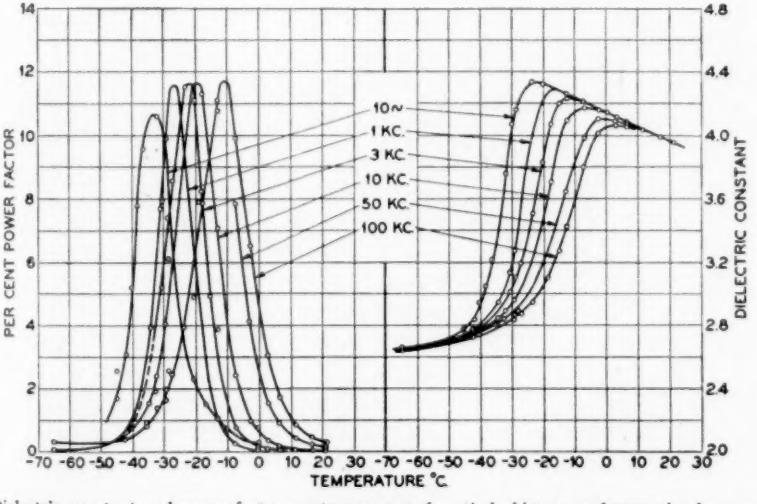
between the dipole and the field. The maxima of power-factor occur near the temperatures where the rate of change

FIG. 2.



Dielectric constant and power-factor vs. temperature for rosin oil No. 2 at frequencies from 10 cycles to 100 kilocycles.

FIG. 3.



Dielectric constant and power-factor vs. temperature for ethyl abietate at frequencies from 10 cycles to 100 kilocycles.

of dielectric constant is greatest. The power-factor maxima for 10 cycles in Figs. 2 and 3 are somewhat lower than for the other frequencies. This, however, is probably due to the

uncertainty of the conductance values at such low frequencies. The maximum conductance for rosin oil No. 2, for example, at 10 cycles in the condenser used was 10×10^{-10} mhos, whereas the accuracy of the measurements was not greater than 2×10^{-10} mhos. This might result in a relatively large error in the value of the power-factor. At higher frequencies the accuracy was much greater and there is no significant difference between the values of the maxima for 1, 10 and 100 kilocycles, except in the case of rosin oil No. 2. Here there are too few points to establish definitely the shape of the maxima at low frequencies although a trend toward a lower value at low frequencies is indicated.

Figures 4 and 5 show the data for rosin oil No. 2 plotted against frequency, temperature being the parameter. The various curves cannot be exactly superimposed upon each other by a displacement along the frequency axis because at each temperature the density is slightly different.

From the curves of dielectric constant vs. frequency it is possible to determine ϵ_∞, the geometric dielectric constant, that is the dielectric constant remaining after all dipole rotation is prevented and due only to distortion of the molecule. This should be made up of two terms, namely that due to electrons and that due to atoms. The electronic part can be determined from the refractive index and is in fact equal to n_∞^2, n_∞ being the optical refractive index extrapolated to the frequency of the electric waves. The remainder then should be the part of the dielectric constant due to atomic displacements. In Table I are given the

TABLE I.

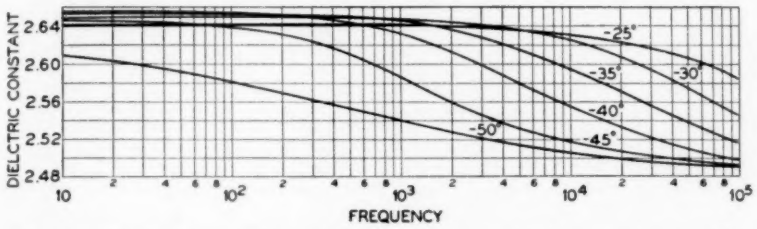
Substance.	ϵ_∞.	n_∞^2.	ϵ_A.
Ethyl abietate	2.60	2.30	0.3
Rosin oil No. 2	2.45	2.35	0.1

values at 20° C. of ϵ_∞, n_∞^2 and the difference, ϵ_A. Because of the extrapolations necessary in calculating these ϵ_∞ values they can be considered only approximate. A sufficiently liberal allowance was made so that the true values are, however, likely to be larger than those given. There is thus

a definite indication that such a term exists and that it constitutes several per cent. of the geometric dielectric constant.

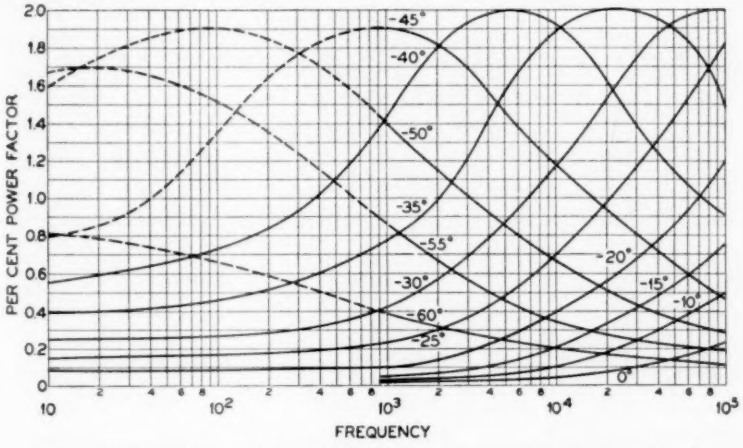
A theory accounting for changes of dielectric constant and power-factor with temperature and frequency which predicts

FIG. 4.



Dielectric constant vs. frequency for rosin oil No. 2 at temperatures from − 25° to − 50° C.

FIG. 5.



Power-factor vs. frequency for rosin oil No. 2 at temperatures from 0° to − 60° C.

a behavior similar to that shown by these substances has been worked out by K. W. Wagner [7] without the assumption of any specific mechanism such as dipoles. Wagner's theory requires that the dielectric to show such behavior be non-homogeneous and that the constituents have different di-

[7] K. W. Wagner, *E. T. Z.*, **36**, 111, 121, 135, 163 (1915).

electric constants and conductances. Wagner has given numerous examples of such behavior.

The Wagner and Debye theories have much in common and it is difficult to determine, in some cases, which of them provides the correct explanation. Indeed they are not mutually exclusive. In many cases it will not be possible without a great deal of experimentation to establish definitely that the dipole is responsible for the losses or that it is due to whatever mechanism accounts for the Wagner effect. However, in other cases it will be possible to show that the losses are predominantly due to one or the other effect. It is believed that the dipole mechanism offers the most probable explanation of these results although these materials might be considered as border-line cases in which both effects may be present.

A mechanism which can explain such changes of dielectric constant and power-factor has been suggested by Murphy and Lowry [8] to explain certain dielectric properties of textiles. This mechanism, which is particularly suited to, though not limited to, colloids, consists in the displacement of adsorbed ions over the surfaces of particles, the ions being constrained to remain on the surface and thus forming polarizable complexes in which an electric moment may be induced by the field. The times of relaxation of such complexes might well be of the same order as those observed in our experiments. The essential difference between the dipole mechanism and that suggested by Murphy and Lowry is that the latter should show an increase of conductivity and decrease of dielectric constant with increasing voltage due to the desorption of ions as the voltage is increased. The dipole mechanism requires, of course, proof of the existence of a dipole moment.

Measurements of direct current conductance have not been made over a wide enough range of voltages to rule out the adsorbed ion explanation. The few measurements which have been made indicate however that the direct current conductivity for voltage gradients up to 1000 volts per cm. is entirely negligible in comparison to the alternating current

[8] E. J. Murphy and H. H. Lowry, *J. Phys. Chem.*, **34**, 958 (1930).

conductance at temperatures where the power-factor maxima occur.

If we were dealing with both a Wagner effect and a dipole effect then it would be expected that the Wagner effect would occur at the lower frequencies and the dipole effect at the high. There should then be two regions where the dielectric constant changed with frequency if the frequency range were sufficiently great. Only one change is observed in the frequency range with which we worked. There is no indication, moreover, from these data that the effects observed are essentially different at low frequencies than at high. If we assume that the decrease in the dielectric constant with frequency which is observed for these materials is the first drop, due to the Wagner effect, then the difference between the value of the dielectric constant after this drop and the square of the refractive index gives the change which might subsequently be caused by dipoles. For rosin oil No. 2 at 20°, for example, this could only result in a decrease from approximately 2.45 to 2.35, the value of the square of the refractive index, entirely neglecting the atomic polarization. For ethyl abietate the change could only be from 2.6 to 2.3. While this is not impossible it appears improbable, at least in the case of ethyl abietate where the existence of a dipole moment is indicated, that the change of dielectric constant due to the dipoles should be so small.

These materials are not well suited to a study of their dipole moment because the rosin oils are mixtures and the ethyl abietate was not of the highest purity. This same behavior, however, has been observed recently in other materials of known purity and structure and it has been shown that without question there is a loss similar to that reported in this paper and in the same frequency range which is due to dipoles. It is expected that this work will be published shortly. It seems quite probable then that the dipole mechanism offers the best explanation of the dielectric behavior of these rosin oils and ethyl abietate.

Nerve Injuries from Electric Shock.—W. B. KOUWENHAVEN AND O. R. LANGWORTHY. (*Electrical Engineering*, Vol. 50, No. 12.) During the last few years these authors have been studying the effect of electricity upon the nervous systems of experimental animals. One series of tests consisted of subjecting rats to a.-c. or d.-c. shocks of 110, 220, 500 or 1000 volts. For the 110- and 200-volt circuits more serious injuries resulted from a.-c. than from d.-c. shock, while with a circuit potential of 500 volts, the effects of a.-c. and d.-c. shock were approximately equal. For circuit potentials of 1,000 volts the d.-c. shock produced a greater injury than the a.-c. shock, particularly when the time of application was taken into consideration.

The results of this investigation would seem to indicate that the ultimate causes of death from electric shock are hemorrhages of the nervous system identified through the appearance of damaged nerve cells. Examination shows that not all nerve cells of a given group are damaged to the same extent from electric shock. Often several normal cells will be found in the midst of those irreparably damaged. Evidence obtained from examination of animals surviving the shock would indicate that some cells have the power of recovery and of being restored to a point where they can once more function normally. Thus, there is a very good and logical reason for conducting prolonged artificial respiration upon a person whose breathing has been stopped through electric shock. This extended forced respiration will give the nerve cells controlling respiration time to recover their normal functioning.

It is interesting to find that the damage done to a nerve cell by electric shock is not at all specific but may also be caused by poisons or physical agents. Very high bodily temperatures may cause cell damage and it is an established fact that body temperature rises rapidly in the case of electric shock if the circuit is closed for any length of time. Shocks produced under various conditions have produced cell injuries caused by excessive temperature in some instances and in others, directly by electrical surges. Another type of cell damage is disclosed in cases where the brain and other remote nerve fibers have become injured when the current merely passed from one hind leg to the other.

T. K. C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RADIO TRANSMISSION OVER LONG PATHS.

During the radio operations of the Byrd Antarctic Expedition it was found necessary to establish a station at Dunedin, New Zealand, for purposes of communication and for observations of radio transmission phenomena. This station was located in an exceptionally fine situation at about 500 feet altitude overlooking the Pacific Ocean.

Regular measurements of the signal strengths of a number of American and European short wave stations were made by means of apparatus prepared at the Bureau of Standards. These measurements extended over a period of several months. The results of this work will be published in the February number of the Bureau of Standards Journal of Research.

Certain observations show that high-frequency signals traveling along paths of prolonged darkness do not remain constant after the path becomes wholly dark, but are subject to a loss, which is greater with the higher frequencies and increases as the darkness is prolonged.

Though signals over long paths are shown generally to increase as the proportion of darkness to daylight along the path is increased, this is not necessarily always the case. Under certain conditions the absorption in the portion of the Kennelly-Heaviside layer under direct radiation of the sun is shown to increase more rapidly than the decrease in absorption due to the gradual approach of darkness along the path.

Among the most interesting of the observations is a violent fading of signals from England shortly before sunrise. A study of this fading indicates that at this time the signal apparently does not follow the great circle path along the earth but appears to come along a path approximately 15° from the great circle path.

During the second voyage of the *City of New York* to the

* Communicated by the Director.

Antarctic, and while in the vicinity of the south magnetic pole, a major magnetic storm occurred. During this time signals faded to a small fraction of their normal value, in most cases disappearing entirely, while at the same time WFA at Little America continued its communications, noting only a small diminution in signal strength. This indicates that the effect was largely localized.

DISTANCE RANGES OF RADIO WAVES.

It is well known that the distances over which practical radio communication is possible vary greatly with the frequency used and with many other factors. The effects of some of these factors can not be predicted. Nevertheless sufficient experience has accumulated so that the distance ranges under average conditions can be fairly well summarized. Such a summary is a valuable guide in radio operations, and is given in a letter circular just prepared by the bureau.

The information is given mainly in two graph sheets, one for day and one for night transmission. The whole range of radio frequencies is covered. The effects of wave transmission along the ground and in the upper atmosphere is explained. A brief bibliography is included.

Anyone having use for the information can secure a copy upon request for Letter Circular 317, "Distance Ranges of Radio Waves," addressed to Bureau of Standards, Washington, D. C.

SOME HIGH COMPRESSIVE STRENGTHS FOR STONE.

Recent tests on samples of quartzite submitted by the United States Engineers Office from the state of Montana gave such unusually high compressive strengths that some curiosity was aroused as to what type of rock really stands highest in this respect. An examination of the test records of this bureau showed the following extreme values for compressive strength:

Quartzite from Montana	63,000 lbs./in.^{2}
Marble from Vermont	50,000 "
Novaculite from Arkansas	44,000 "
Granite from Maryland	42,000 "
Limestone from Tennessee	40,000 "
Sandstone from Wisconsin	29,000 "

Even the highest of these is somewhat lower than a test made some time ago in Germany on basalt which gave 67,000 lbs./in.^{2} Such high strengths can be better appreciated by computing the height of a self-sustaining wall of the materials. For example, the quartzite having a weight of 165 pounds per cubic foot would have to be built up over ten miles high before failure would occur from crushing.

In general, it may be said that the values given above are from two to four times the average strength of the various types named, except for novaculite which is probably not far from the average.

RESISTANCE TO ABRASION OF A SILLIMANITE PORCELAIN DIE WHEN USED FOR EXTRUDING CLAY COLUMNS.

A concern manufacturing spark plug porcelain has equipped its extrusion machines with "sillimanite" porcelain dies for extruding "spark plug blanks." The batch composition of the porcelain consists very largely of andalusite, which has a hardness of 7.5 (Moh's scale), or 0.5 greater than the hardness of quartz.

Twelve tests were made on each of duplicate specimens of porcelain dies furnished by the manufacturer. Although tests on the duplicate specimens checked very closely, successive tests showed increasing abrasion losses. The hard "skin" which occurs on well vitrified porcelain is similar to that on glass and inasmuch as the tests showed that this hard skin decreased in service value whith depth as abrasion progressed, the service values $C^{1/n}$ were determined for each of the twelve duplicate tests. These were determined from the equation $C^{1/n} = X^{1/n} \div Y$, in which "n" = 0.645, "X" = extrusion pressure, and "Y" = abrasion loss. The service values varied from 107.17 at the end of the first test to 66.25 at the end of the twelfth. At the end of the twelfth test the depth of the material removed was 0.1164 mm, or approximately 0.004584 of an inch.

The service values when plotted against depth gave a hyperbolic curve which is expressed by the equation: $(U - A)(V + B) = K$, in which "U" is service value, "V" = depth in mm. "A" = 45.78, "B" = 0.04622, and "K" = 3.235.

At the surface (when "V" = O) the service value as de-

termined by calculation is 115.76. Whether the relation between depth and service value continues according to this hyperbolic equation beyond the experimental limits is not known. If, however, it is assumed that the relation does continue even to an infinite depth, the service value of the porcelain cannot fall below the value of "*A*," which is 45.78.

TENSILE PROPERTIES OF RAIL STEELS AT ELEVATED TEMPERATURES.

It is believed by many that shatter cracks, which are usually found in the heads of rails failing from transverse fissures, are caused by stresses, set up while the rail is on the cooling bed, which, in turn, are caused by temperature gradients in the rail sections; also that shatter cracks serve as nuclei from which transverse fissures subsequently develop in service.

Elevated temperature tensile tests have shown that rail steels are markedly brittle in the neighborhood of 550° C. which is known as the secondary brittle range. It is thought that shatter cracks form in some rails when they cool in the ordinary way through this range of low ductility.

Tests reported in the February number of the Bureau of Standards Journal of Research show that slower cooling from the hot saw increases the ductility in the secondary brittle range but decreases it somewhat at about 400° C., so that the ductility curves for the slowly cooled rails fluctuate less than those for normally cooled rails.

There was no difference in the tensile properties of fissured and unfissured rails that had been subjected to the same service. Tests were also made on rails from a mill whose product had a poor service record and on rails from the same mill made subsequently when the product was yielding better service records. Although the ductility of all of these rails did not show a sharp inversion in the secondary brittle range, the values were low at elevated temperatures. Shatter cracks were found in all of the rails that failed in service from transverse fissures, whereas no cracks were found in rails that had been subjected to the same service without failures. Tests on a medium manganese rail deoxidized with zirconium showed this rail also to have marked secondary brittleness.

NEW CIRCULAR ON ZINC.

Although zinc has been used for generations and in the form of the alloy, brass, dates back to antiquity, it is in many respects a modern metal. Not until within the past decade has the metal been systematically studied and its properties carefully determined. Circular No. 395 of the Bureau of Standards which has just been issued, is devoted to this metal and its alloys. It contains a wealth of information on zinc, summarized from the technical literature and supplemented by the results of tests carried out at the bureau. This publication follows the general lines of others on the properties of metals and alloys which have been issued by the bureau and which include circulars on copper, nickel, aluminum, and bismuth.

Zinc is now available commercially in a state of very high purity. Recent improvements in both the smelting process and the electrolytic process have made available metal with a zinc content close to 99.99 per cent. Zinc of very high purity has been found to be extremely resistant to corrosion by most of the common acids.

On account of the relative ease with which zinc can be produced in large crystals, a great deal of study has been devoted to the properties of the metal in the form of single crystals and much light has been thrown on the subject of its plastic deformation.

Zinc crystallizes in the hexagonal system, and the basal hexagonal planes, that is, the planes perpendicular to the principal crystalline axis, are the ones upon which deformation by slip readily occurs. A crystal stressed so that slip on basal planes can readily occur shows extremely high ductility. The same crystal when stressed in other ways will show practically no ductility

Recent studies carried out on the extremely pure zinc now available have not supported the statements previously made by other investigators concerning the allotropy of zinc. Zinc, evidently, exists in only one crystalline form.

Although sheet zinc possesses very good tensile strength, it is not in the same class with sheet steel or iron. Zinc is much more ductile, and when maintained for long periods of time under sustained loading, it may "creep" or sag. This

property of zinc must be borne in mind if it is to be used to best advantage in roofing and for other building purposes. The ordinary rules of construction have been developed for other materials and should not be applied indiscriminately to any and all materials of construction.

By far the greatest outlet for zinc is in galvanizing. In this country nearly half of the zinc produced annually is used for this purpose. Zinc coating by galvanizing, that is, dipping in molten zinc, is possible because of the ready alloying which occurs between liquid zinc and iron. This makes it possible for the metal to "wet" the iron surface, a circumstance not possible with some metals, for example, lead.

Of the alloys of zinc, brass is by far the most important. The properties of brass are closer to those of copper than of zinc since zinc is the minor constituent. Of the zinc-rich alloys, those used for die-casting purposes are the most important. The alloys which are most used in this country are those of zinc, copper, and aluminum; the zinc constituting over 90 per cent of the whole. Great advances have been made in the die casting art and in the preparation of the die-casting alloys. Those materials are widely used and may be regarded as entirely reliable for the uses for which they are developed.

The circular contains many half-tones, graphs, and tables which add greatly to its value for reference purposes. Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 70 cents apiece.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, FEBRUARY 17, 1932.

The regular monthly meeting of the Institute was called to order at eight-fifteen P.M., with Mr. W. C. Wetherill, Vice-President, presiding. He immediately called upon the Secretary for a statement of the business of the evening.

The Secretary stated that the minutes of the January meeting of the Institute had been published in full in the JOURNAL of the Institute for February, and suggested that the minutes be approved as printed. The Chairman asked if there were any objection and upon hearing none, announced that they were approved as printed.

The Secretary reported, concerning membership, that there had been the following additions: six Resident members; seven Non-Resident members; and one Student member. He reported, also, with extreme regret, the death of two highly honored and long time members of the Institute—Dr. George F. Stradling, Principal of the Northeast High School, and Mr. Stephen H. Noyes, a member of the Pennsylvania Railroad organization. He stated that both of these gentlemen had been active in the affairs of the Institute for years, that their services would be greatly missed and their deaths deeply mourned.

The Secretary announced that, upon the recommendation of the Committee on Science and the Arts, the Board of Managers of The Franklin Institute had awarded Franklin Medals to Professor Dr. Philipp Lenard, Professor of Physics in Heidelberg, Germany, and to Dr. Ambrose Swasey of Cleveland, Ohio, and that it is customary for the Institute to elect to Honorary Membership those to whom Franklin Medals are awarded. The Board of Managers therefore recommends to the Institute Professor Dr. Philipp Lenard and Dr. Ambrose Swasey for election to Honorary Membership.

The Secretary stated further that the Board of Managers wished to recommend one additional person to Honorary Membership—a gentleman who had been an inspiring teacher of physics for forty years, who had written a popular and successful text book on physics, and who for many years had been the Executive Secretary and the mainspring of action of the Committee on Science and the Arts, thereby promoting greatly the purposes of the Institute; namely: Dr. George A. Hoadley.

He therefore suggested that some member of the Institute move the election of the three gentlemen named to Honorary Membership in The Franklin Institute. This motion was offered and seconded and adopted unanimously.

Announcement was then made by the Secretary of the appointment by the President of the following two committees of the Institute:

Committee on Library

C. W. Bates
H. J. Creighton
W. G. Ellis
F. Lynwood Garrison
C. A. Hall
J. S. Hepburn
G. A. Hoadley
L. F. Levy
T. S. Rowland
W. T. Taggart

Committee on Meetings

James Barnes
George S. Crampton
T. G. Delbridge
W. H. Fulweiler
A. W. Goodspeed
Howard McClenahan
Charles Penrose
G. D. Rosengarten
James G. Vail
W. C. Wagner

He further announced that at the Organization meeting of the Board of Managers, the following twenty gentlemen had been either elected or re-elected for a term of three years to membership in the Committee on Science and the Arts, and that, at a meeting of that Committee held last week, Mr. Edward L. Clark had been elected Chairman of the Committee for the year 1932:

Henry Butler Allen
C. W. Bates
Hugo Bilgram
William L. Brown, 3rd
Edward L. Clark
Theobald F. Clark
Theodore K. Cleveland
Thomas D. Cope
William G. Ellis
William H. Kavanaugh
W. Laurence LePage
Charles H. Masland, 2nd
Frederic Palmer, Jr.
M. M. Price
James S. Rogers
Samuel Shoemaker
Warren P. Valentine
Francis R. Wadleigh
Robert L. Wood
Winthrop R. Wright

The Secretary finally announced that on the programme of meetings which had been sent to the membership, March third had been listed as an open date. This date has now been filled by a lecture to be given by Dr. E. Newton Harvey, Professor of Physiology in Princeton University, who will talk on the subject, "The Microscope-Centrifuge and Some of Its Applications." Professor Harvey will describe the action of this type of microscope, will demonstrate it, and will outline some of the striking results which have been obtained by its use.

There was no further business, therefore the Chairman at once introduced Mr. Harden F. Taylor, President of the Atlantic Coast Fisheries Company, who lectured delightfully on "Resources of the Ocean." As illustrative of the mass of materials held in suspension in ocean waters, the speaker used figures which seemed almost astronomical in magnitude. The lecture was very gratefully received and was followed by some questions and discussion.

The meeting adjourned at nine-forty-five P.M., with an expression of appreciation to Mr. Taylor by the Chairman of the evening, Mr. Wetherill.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, February 10, 1932.)

HALL OF THE COMMITTEE
PHILADELPHIA, FEBRUARY 10, 1932.

MR. LIONEL F. LEVY *in the Chair.*

The Chairman announced the reëlection by the Board of Managers of nineteen members of the Committee to serve for three years and the election of one new member to serve for the same period.

The Special Committee on Nomination of a Chairman for the ensuing year reported as its choice Mr. Edward L. Clark. Mr. Clark was unanimously elected and took the Chair.

The following reports were presented for final action:

No. 2922: Work of Doctor Bridgman in High Pressure.

This report recommended the award of the Elliott Cresson Medal to Doctor Percy W. Bridgman, of Cambridge, Massachusetts, for his "fundamental contributions to the technique of high pressure experimentation and his extension of the range of high pressures available in the laboratory."

No. 2944: Toledo Scales.

This report recommended the award of the John Price Wetherill Medal to Mr. Halvor O. Hem, of Toledo, Ohio, "In consideration of the ingenuity shown in perfecting scales of the pendulum type, improving their accuracy, reliability and sensitiveness, and for his application of these scales to specific purposes."

No. 2950: Franklin Medal.

This report recommended the award of the Franklin Medal to Doctor Ambrose Swasey, of Cleveland, Ohio, "In recognition of his development of methods and his invention of appliances for making machines, tools, and instruments of the highest precision, of the design and construction of the mountings of many of the world's largest telescopes, and of his scientific vision in the establishment of the Engineering Foundation for the promotion of research and its application in the various fields of engineering."

The following reports were presented for first reading:

No. 2946: Diffraction of Electrons by Thin Films.
No. 2952: Clark Medal.
No. 2953: Literature.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, February 17, 1932.)

RESIDENT.

MR. CLAIRE H. JEGLUM, Chemist, Philadelphia Quartz Company, 121 South Third Street, Philadelphia, Pa.

MR. ROBERT MCLEAN, Newspaper Executive, Bulletin Company, 202 Bulletin Building, Philadelphia, Pa.

MR. C. RICHARD SODERBERG, Engineer, Westinghouse Company, Lester Branch Post Office, Philadelphia, Pa. For Mailing: 9 Swarthmore Crest, Swarthmore, Pa.

NON-RESIDENT.

MR. FREDERICK O. BALL, Research Engineer, Chrysler Corporation, Detroit, Michigan. For Mailing: 941 Longfellow Avenue, Detroit, Michigan.

STUDENT.

MR. RICHARD H. BRUCE, Student, Temple University, Philadelphia, Pa. For Mailing: 205 Leon Avenue, Norwood, Pa.

CHANGES OF ADDRESS.

MR. A. W. K. BILLINGS, c/o Rio de Janeiro Tramway, Light and Power Company, Ltd., Caixa do Correio 571, Rio de Janeiro, Brazil.

DR. JOSEPH C. BOYCE, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

MR. E. W. CLARK, 1531 Locust Street, Philadelphia, Pa.

MR. ERNEST AINSLEY FAIRMAN, Silviculturist, 22 Vernon Street, Halifax, Nova Scotia, Canada.

MR. WILLIAM H. GARTLEY, 101 Gowen Avenue, Mt. Airy, Pa.

DR. ARTHUR R. KNIPP, 29 Shaler Lane, Cambridge, Mass.

MR. JACQUES L. VAUCLAIN, 848 Buck Lane, Haverford, Pa.

MR. SIGURD WESTBERG, 310 Orange Street, New Haven, Connecticut.

MR. VICTOR W. ZILEN, 3214 Rosemont Drive, Chattanooga, Tennessee.

NECROLOGY.

Mr. Stephen H. Noyes, Philadelphia, Pa.

Dr. George F. Stradling, Germantown, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

BRIDGMAN, P. W. The Physics of High Pressure. 1931.

Bulletin Almanac and Year Book, 1932.

CARNEAL, GEORGETTE. A Conqueror of Space. An Authorized Biography of the Life and Work of Lee De Forest. 1930.

CLAYTON, WILLIAM. Colloid Aspects of Food Chemistry and Technology. 1932.

FAJANS, KASIMIR. Radioelements and Isotopes: Chemical Forces and Optical Properties of Substances. 1931.

FINDLAY, G. M. Recent Advances in Chemotherapy. 1930.

FISH, FLOYD HAMILTON. The First Course in Quantitative Analysis, Containing a Group of Lectures and Laboratory Experiments. 1931.

GASSENDI, PIERRE. Tychonis Brahei, Equitis Dani, Astronomorum Coryphæi, Vita. Editio secunda, auctior et correctior. 1655.

GUDDEN, BERNHARD. Lichtelektrische Erscheinungen. 1928.

HALE, GEORGE ELLERY. Signals from the Stars. 1931.

Johann Kepler, 1571–1630. A Tercentenary Commemoration of his Life and Work. A series of papers prepared under the auspices of The History of Science Society in collaboration with The American Association for the Advancement of Science, Sections A, D, and L. 1931.

JOHNSON, FREDERICK W. Non-interpolating Logarithms, Cologarithms and Antilogarithms. 1930.

LEA, MATHEW CAREY. Kolloides Silber und die Photohaloide. In deutscher Übersetzung mit Anmerkungen, neu herausgegeben von Dr. Lueppo-Cramer. 1908.

MAHON, CHARLES, VISCOUNT. Principles of Electricity, Containing Divers New Theorems and Experiments, Together with an Analysis of the Superior Advantages of High and Pointed Conductors. 1779.

PARRY, ERNEST J. The Chemistry of Essential Oils and Artificial Perfumes. Fourth edition, revised and enlarged, two volumes. 1921–1922.

POUCHER, WILLIAM A. Perfumes, Cosmetics and Soaps, with Especial Reference to Synthetics. Third edition. Two volumes. 1929–1930.

STYLE, D. W. G. Photochemistry. No date.

World Almanac and Book of Facts for 1932.

WYCKOFF, RALPH W. G. The Structure of Crystals. Second edition. 1931.

BOOK REVIEWS.

QUANTITATIVE ANALYSIS. By F. H. Fish, Professor of Analytical Chemistry, The Virginia Polytechnic Institute. 120 pages, ill., 12mo. P. Blakiston's Son & Co., Inc., Philadelphia, 1931. Price $1.25.

It is the author's conviction that "A definite prescribed course with no 'tentative' or optional methods is the only course a beginner can absorb clearly." Instructors sharing the same views will want to examine this book. But while simplification is a valuable ideal, it has its dangers, and it is this reviewer's opinion that the subject is over-simplified. Such a text throws heavy demands upon the time, skill and experience of the instructor if the student is to gain perspective. The student finishing such a course ordinarily will entertain false confidence in his ability as an analyst.

The procedures are presented as "Experiments." No division is made between gravimetric and volumetric methods. Part I is addressed to engineering and applied science students and contains the following experiments: Use of Bal-

ance—Use of Indicators—Preparation and Standardization of HCl and NaOH Solutions—Determination of Iron and Sulphate—Determination of Iron by Dichromate Method—Standardization of Permanganate—Standardization of Thiosulphate—Determination of Copper—Volhard's Method for Chlorine or Chlorides—Limestone Analysis. Part II, for agricultural or home economics students, incorporates the early experiments of Part I and in addition, Crude Protein Determination on a Feed—Moisture Determination—Ether Extract (Fat)—Ash Determination in Feeds—Crude Fiber—Fertilizer Analysis—Determination of P_2O_5 in Fertilizers, Total and Available P_2O_5.

The arrangement reminds one strongly of freshman laboratory manuals. Frequent problems are interspersed. Tables of five place logarithms and a chart of the common indicators are included. There are a few misprints and some looseness of expression. It is rather unusual to find carbonate-bicarbonate mixtures turning phenolphthalein "purple" (p. 22). A considerable tendency is shown to bring over material which should have been thoroughly mastered in earlier courses. The reviewer looks forward to the time when "cc." shall retire from quantitative texts in favor of "ml."

The book will find a place in courses of simple character where time is short and theory can be neglected. There is more in it for agricultural students than other groups and very little of home economics interest.

LESLIE R. BACON.

RADIOELEMENTS AND ISOTOPES: CHEMICAL FORCES AND OPTICAL PROPERTIES OF SUBSTANCES. By Kasimir Fajans, University of Munich. The George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University. x–125 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc., 1931. Price $2.50.

This book is not an exact word for word account of what the author said in his lectures before the students of Cornell during his holding of the George Fisher Baker non-resident lectureship in chemistry. Dr. Fajans has intentionally edited his lectures in order that the book will not contain too much regarding the more elementary concepts of atomic structure, quantum theory, radioactivity and isotopy. On the other hand, he has dealt in more detail with those phases of chemical research that have held his attention for many years.

Dr. Fajans is deeply interested in the fundamentals of atomic structure and the forces responsible for the specific chemical and physical behavior of atoms and molecules. His book begins with his introductory lecture to his audience at Cornell. In this he traces in a very interesting manner the development of views regarding the nature of chemical forces. It was not a short step from the mechanical views of Galileo, Keppler and Newton to the wave mechanics of de Broglie, Heisenberg and Schrödinger. It required three centuries of many intermediate theories, each succeeding one appearing to come a little closer to the truth.

A chapter on the origin of the actinium series and the stability of isotopes stands off from the remainder of the book. Accumulated evidence appears to deny any genetic relationship between actinium and uranium. On the other hand, actinium is found only in uranium minerals and it is possible that it originates from some long-lived isotope of uranium (actino-uranium).

The remainder of the volume comes under the heading: "Chemical Forces and Optical Properties." After an introductory chapter on atomic and crystal structures, attention is turned to a consideration of chemical compounds showing an ideal ionic linkage. Apparently the deformability of ions is quite general once they have combined to form molecules. The extent of this deformability may be shown by studying changes in the refractivities of the ions when combined with other ions. Transitions between ideal ionic linkages and non-polar linkages are interestingly brought out through consideration of such properties as melting points and conductivities in a series of chlorides of sodium, magnesium, aluminum and silicon. The study of the absorption of ions upon salt-like crystals bears directly upon the method for precipitating from solution substances present in such low concentration they are not exceeding their limit of solubility. A practical example is the precipitation of radium along with barium sulfate. The property of adsorption has found a still wider application in which certain dyes act as indicators for volumetric analyses by becoming adsorbed at the critical moment and producing a solar change. The final chapter deals with a number of photochemical applications of ion adsorption. Here, adsorbed ions appear to exert a positive influence upon the absorption of light by the light sensitive silver halides.

The book is written in an engaging manner and the illustrations have added much to its appreciation. Numerous references to original papers are made and the book is supplied with both an author and subject index.

T. K. CLEVELAND.

PHOTOCHEMISTRY. By D. W. G. Style, with a Preface by A. J. Allmand, Monographs on Physical Subjects. 96 pages, illustrations, 12mo. New York, E. P. Dutton & Co. Price $1.10.

This little volume becomes more impressive as one reads its five chapters. The author has treated his subject from a broad point of view but has in no wise attempted a treatise. The exposition is notably clear and the examples chosen for illustration are adequate but to the point.

Chapter I is introductory to the subject. The other chapters are entitled—The Primary Light Process—Secondary Chemical Processes, Chain Reactions—The Dependence of the Quantum Yield on Temperature and Wave-Length—Experimental Methods. While the simple style of exposition and the careful selection of examples to illustrate specific points may "suggest a stability which may, in fact, be non-existent" in the author's own words, he is not unaware of this and provides a selected bibliography. The reviewer was disappointed to find only a few lines devoted to the photochemistry of the silver halides and no discussion of photosynthesis.

With due allowance for lack of completeness, such a book can be read with much profit both as an introduction and as a conclusion to a course in photochemistry. With a minimum of effort the beginner can gain sufficient acquaintance with principles, methods and general scope of the subject to better orient his more critical study, while the advanced student will be thankful for the author's ability to keep essentials afloat on the flood of data, formulations and abstractions of theory and principle which always characterize the rapid expansion of such a field.

LESLIE R. BACON.

NON-INTERPOLATING LOGARITHMS, COLOGARITHMS AND ANTILOGARITHMS. By Frederick W. Johnson, Instructor in Chemistry, California College of Pharmacy. 21 pages, tables, 8vo. San Francisco, The Simplified Series Publishing Co., 1930. No. 2 of the Simplified Series of Science Helps. Price $2.25. (Fabrikoid binding.)

It may seem strange to find that logarithmic tables can take new forms but this volume appears to be a departure from previous compilations. Here we find tables so arranged as to give four and five place logarithms and antilogarithms and four place cologarithms without the use of proportional parts or any interpolation whatever. The new arrangement makes it possible to find the exact mantissa for every number up to 100,000 by mere reference to the five place logarithmic tables, and the converse holds for the table of five place antilogarithms. It is said that tables arranged in the usual manner would require 380 pages to give by direct reading all that is included in the 76 pages comprising the tables of five place logarithms and antilogarithms. There is more merit, however, in these tables than the mere avoidance of interpolation and the conservation of space because of the fact that the values here given are exact whereas by interpolation with the usual tables, even when accurately done, it is not uncommon for the last figure of the mantissa to be positively in error.

That unusual care has been taken in the preparation of these tables seems to be evidenced by the offer on the title page of a complimentary leather bound copy of the book to the first person reporting an error in any individual figure; a number of errors in other compilations are pointed out. In order to secure the best arrangement, it is said that 58 different proofs of a portion of the tables were set up, printed and subjected to criticism, representing even then only a small fraction of the total number of plans worked out. A critic may well bethink himself before suggesting means of further improvement, yet this reviewer, on the basis of practical experience, ventures to suggest that if vertical lines were added preceding the fourth figure of the logarithms or antilogarithms in the five place tables considerable might be gained in speed and reduced mental fatigue. This is particularly in point with respect to the first part of the logarithmic table and the last part of the antilogarithmic table which at first appear rather bewildering. While the print is clear, the reviewer also has found himself occasionally making mistakes with respect to the third and fourth figures of the value sought on account of insufficient contrast between the type with which these are printed and that with which the fifth place value is given. This might be remedied if the latter were reduced to the size type now used where the fifth place figures are overscored or even by replacement by a dot except where the fifth place value changes.

In addition to tables before mentioned there are others for the reduction of small angles to seconds, formulas for the use of S, T, CS and CT (functions useful in connection with small angles), International atomic weights (for 1925, unfortunately out of date) including their logarithms and cologarithms, likewise logarithms and cologarithms for metric conversion factors, mathematical constants and decimal equivalents of all common fractions. There are 23 pages of introduction which set forth definitions, principles and the use of the tables. Some effective illustrations of the saving in time and energy through the combined use of logarithms and cologarithms, especially in the solution of chemical

problems, are given. There are a number of non-misleading errors in the table on page 12 with respect to the placing or omission of decimal points, and also a misprint in Exercise 4, page 19, where the numerical statement of the problem fails to correspond with the solution given. It is believed that the actual tables have been much more carefully prepared than has some of the accessory information.

While this reviewer believes that one ordinarily skilled in interpolation will not be at any disadvantage in speed using the older style tables, the contrary will probably be true with respect to antilogarithms with the tables as now presented. The ultimate accuracy with the new tables will be greater. The five place tables can be recommended as sufficiently accurate for nearly every form of calculation in experimental science. One skilled in the use of logarithms, antilogarithms and cologarithms as here presented will be at relatively little disadvantage against another provided with hand operated calculating machines.

The book is attractively bound, printed on good paper, thumb indexed and has other minor features of utility not found elsewhere. It may be had in three bindings, limp cloth, fabrikoid or full leather. Other volumes of mathematical data are promised in extension of the Simplified Series.

LESLIE R. BACON.

LICHTELEKTRISCHE ERSCHEINUNGEN. Von Bernhard Gudden. Struktur der Materie. Vol. 8, 325 pages, diagrams, 8vo. Berlin, Julius Springer, 1928. Price 24 marks.

In his preface to "Photoelectric Phenomena" the author states his book represents an attempt to present clearly our present knowledge as well as ignorance concerning electron emission as a result of the absorption of light. All throughout, emphasis has been placed upon the experimental facts which are critically examined in respect to their reliability or deficiency. The theoretical aspects of the subject, apart from those fundamental to the quantum theory, have been purposely omitted. Only when some experimentally founded hypothesis appeared to him to be questionable or unproven does the author take a brief cognizance of the theoretical reasons for its justification. In spite of the casual treatment of the theoretical phase the author believes the mathematical physicist will receive inspiration from such presentation of observed facts.

Since all phases of the subject cannot receive equal attention due to the limited scope of the book, the author has personally discriminated just as to where the emphasis shall be placed. He has sought to keep away from giving mere summaries and tabulation of data but instead has arranged the facts so as to give an integrated view of the subject which will be of considerably greater value to the reader. The author has not hesitated to express his own views in many instances and hopes that if wrong, such expression will lead to investigations which will provide positive proof either one way or the other.

Methods of measurement are described only when they are considered necessary for imparting a better comprehension or appraisal of the results. The chapters on high frequency effect, selenium cells, Becquerel effect, photochemistry etc., were not written for the benefit of the workers in these fields but for the purpose of rounding out the subject.

The subject matter is arranged under two general headings, "external" and "internal" photoelectric effects. The former includes the effects found in gases and on metallic surfaces. In addition the photoelectric effects for alkalies and alkali earths are described and their practical applications outlined. The "internal" effects in crystals are described, particular attention being paid to semiconducting crystalline substances such as selenium. The balance of the chapters cover in a more general way such miscellaneous subjects as fluorescence, phosphorescence, fading of colors, photochemistry, alkali-metal and mercury vapors. Compton effect, Becquerel effect, phototropism and the Weiger effect.

The book has an extensive bibliography on the subject and the author and name indexes are followed by a table of the more important constants and conversion factors.

T. K. CLEVELAND.

TECHNISCHES WÖRTERBUCH III: DIE WICHTIGSTEN AUSDRÜCKE DER ELEKTRO- UND RADIOTECHNIK. Erster Teil: Deutsch-Englisch, Ed. 2, 157 pages, 16mo. Sammlung Göschen Band 1041. Berlin, Walter de Gruyter & Co., 1931. Price Rm. 1,80.

This handy little pocket-sized book is representative of the importance now accorded the electrical and radio engineering fields. Both the fields of chemistry and physics have enjoyed for some time the distinction of German-English dictionaries compiled exclusively of the terms and expressions peculiar to these branches of science. Now we have from Germany a German-English technical dictionary containing the more important terms used in electrical and radio engineering.

This book should prove of great aid to electrical engineers, professors, students and those professionally engaged in the translation of technical articles written in German. It contains about 10,000 words describing the more important elements of electrical mechanisms such as dynamos, motors, transformers, converters, networks for strong and weak currents, telegraphs, telephones, general communication systems as well as the principal terms of radio engineering. The author also has included those mathematical, physical and chemical terms one might encounter while reading this type of literature. In addition, he has been prevailed upon to include such commercial terms as might be used in the business of buying and selling merchandise of the above nature.

T. K. CLEVELAND.

ECONOMIC CONTROL OF QUALITY OF MANUFACTURED PRODUCT, by W. A. Shewhart, Ph.D., Member of the Technical Staff, Bell Telephone Laboratories, Inc., 501 pages, tables, diagrams, 8vo. New York, D. Van Nostrand Company, Inc., 1931. Price $6.50.

Dr. Shewhart opens his closely written treatise on controls by a philosophical aside on the fly-leaf:

"When numbers are large, chance is the best warrant for certainty." A. S. Eddington, Nature of the Physical World.

A similar reflection from The Logic of Modern Physics by P. W. Bridgman leads the innocent reader to conclude that the author has divested himself of cocksureness, at least. His book, however, is bottomed on a very great deal of ex-

perience in determining the bases of control. After a brief introduction into the problem and nature and definition of control, Chap. II relieves the suspense by establishing a scientific basis, for control. Without exhausting the wanderings of molecules (within limits), the variation of defectives, or the fluctuations of a product one can receive the conclusion that criteria can be established to the enormous benefit of industry.

Part II of the book is assigned to a discussion of the expression of quality or rather the expression of the quality of a product that can be expressed, as a graph, as arithmetic, as statistics, as a ratio, as a coefficient, or even as a skewness or a flatness. One must define. In Chaps. X to XII the Laws basic to control are illustrated by illustrations that testify to an enormous amount of work in this field of physical research. Part IV restates the problem by an intimate discussion of sampling fluctuations. To the manufacturer who is struggling to establish tolerances for his product, minima below which he will have rejects and maxima above which he cannot afford to go, the fifth part of this book (Chaps. XVII and XVIII) will appeal. There is of course the proviso of whether he can read the language. Almost as important as the limits of a desired quality is the understanding when variations can be allowed. The sixth part of the book explains five criteria for determining when variations in quality cannot be left to chance.

To be informed one should arrive at the last stage of the book by the preparatory work. I have a suspicion that some few laymen will go by air directly to those pages that discuss the problems of sampling and the measurement of quality that depends on intelligent and correct sampling. Fig. 141 shows a coil of wire. How should one choose a random sample to test the tensile strength? Or, again, how should one choose a pole from a yard of poles? Relatively few people have to choose a soldered terminal in a PBX panel but there is the question faced by someone; of how to choose? Except for appendices, the book ends with a control program.

Eddington may be right. I am reminded, however, of the comment of Abraham Lincoln when he labored to follow a treatise exhaustive. He turned to his friend, it is said, with the remark—"Some people like that sort of thing. Anyone who likes that sort of thing would like that sort of thing very much."

HOWARD W. ELKINTON.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 401, Combustion in a High-Speed Compression-Ignition Engine, by A. M. Rothrock, 17 pages, illustrations, quarto. Washington, Superintendent of Documents, 1931. Price fifteen cents.

An investigation, conducted by the National Advisory Committee for Aeronautics, to determine the factors which control the combustion in a high-speed compression-ignition engine is presented. Indicator cards were taken with the Farnboro indicator and analyzed according to the tangent method devised by Schweitzer. The analysis shows that in a quiescent combustion chamber increasing the time lag of autoignition increases the combustion efficiency of the engine and also increases the maximum rate of combustion. Increasing the maximum rate of combustion increases the tendency for detonation to occur. The results show that by increasing the air temperature during injection the

start of combustion can be forced to take place during injection and so prevent detonation from occurring. It is shown that the rate of fuel injection does not in itself control the rate of combustion.

Report No. 402, Effect of Orifice Length-Diameter Ratio on Fuel Sprays for Compression Ignition Engines, by A. G. Gelalles, 14 pages, illustrations, quarto. Washington, Superintendent of Documents, 1931. Price fifteen cents.

Experimental results on the effect of the length-diameter ratio of the orifice on the spray characteristics, together with a brief analysis of the factors affecting these characteristics, are presented in this report. The length-diameter ratios tested ranged from 0.5 to 10; the orifice diameters from 0.008 to 0.040 inch; and the injection pressures from 2,000 to 8,000 pounds per square inch. The density of the air into which the fuel was discharged was varied from 0.38 to 1.35 pounds per cubic foot.

When a plain stem was used in the injection valve and the length-diameter ratio of the orifice was increased from 0.5 to 10, the rate of spray-tip penetration at first decreased and reached a minimum between the ratios of 1.5 and 2.5; then reached a maximum between the ratios of 4 and 6; and decreased again as the ratio was increased to 10. The exact position of the maximum and minimum points depended upon the orifice diameter. The spray cone angle was affected very little by the variation of either the diameter of the orifice or the length-diameter ratio tested at ratios greater than 4.

With a helically grooved stem in the injection valve the ratios at which the highest penetration occurred varied between 5 and 7. The spray cone angle increased with the ratio of the orifice area to groove area.

Report No. 403, Ice Prevention on Aircraft by Means of Engine Exhaust Heat and a Technical Study of Heat Transmission from a Clark Y Airfoil, by Theodore Theodorsen and William C. Clay, 24 pages, illustrations, quarto. Washington, Superintendent of Documents, 1931. Price twenty cents.

This investigation was conducted by the National Advisory Committee for Aeronautics to study the practicability of employing heat as a means of preventing the formation of ice on airplane wings. The report relates essentially to technical problems regarding the extraction of heat from the exhaust gases and its proper distribution over the exposed surfaces. In this connection a separate study has been made to determine the variation of the coefficient of heat transmission along the chord of a Clark Y airfoil.

A study of heat transmission from the airfoil reveals that the local transmission is very high at the leading edge and that it decreases rapidly to a minimum value at a point located about 30 per cent back along the chord.

Experiments on ice prevention both in the laboratory and in flight show conclusively that it is necessary to heat only the front portion of the wing surface to effect complete prevention.

The relative merits of various methods of ice prevention by means of heat are analyzed with the result that a vapor system is found to offer the most satisfactory solution, especially for airplanes which are not constructed entirely of

metal. In "all-metal" designs it may be entirely practicable to employ a direct exhaust-heating system.

A narrow slot on the upper surface located about one-tenth of the chord length from the leading edge is employed in these tests for the purpose of collecting the water which would otherwise blow back and freeze aft of the heated leading edge. The tests seem to indicate, however, that this slot may not be essential.

Report No. 404, The Effect of Increased Carburetor Pressure on Engine Performance at Several Compression Ratios, by Oscar W. Schey and Vern G. Rollin, 12 pages, illustrations, quarto. Washington, Superintendent of Documents, 1931. Price ten cents.

The object of this investigation was to determine the effect of increasing the carburetor pressures from 30 to 40 inches of mercury, at compression ratios from 3.5 to 7.5, on the power, on the maximum cylinder pressures, on the fuel consumption, and on the other performance characteristics of an engine. The tests were conducted on the N.A.C.A. single-cylinder universal test engine by the staff of the National Advisory Committee for Aeronautics. A Roots-type aircraft-engine supercharger was used to maintain the desired carburetor pressure.

The results of these tests show: That the decrease in brake thermal efficiency with boosting is negligible; that the power increases with boosting much more than the losses to the cooling water increase; that a large increase in power can be obtained with comparatively small increase in maximum cylinder pressures; and that it is advisable to supercharge an engine of highest practicable compression ratio consistent with the degree of supercharging desired and the non-detonating quality of the fuel used because the power increase will be greater, the exhaust gas temperatures will be lower, and the power required by the supercharger to maintain the same pressure at the carburetor will be less.

APPLIED GYRODYNAMICS, FOR STUDENTS, ENGINEERS AND USERS OF GYROSCOPIC APPARATUS. By Ervin S. Ferry, Professor of Physics in Purdue University. xiv–277 pages, 8vo, cloth. New York, John Wiley & Sons, Inc., 1932. Price $4.00.

It was many years after Foucault employed the gyroscope to demonstrate the diurnal rotation of the earth that this remarkable device received application in the arts although many pages were devoted to its analysis by numerous writers of note. One of the first striking applications was in controlling the course of the famous Whitehead torpedo. The uncanny ability of the gyroscope to maintain the torpedo upon a desired course aroused widespread interest. That it continued to perform satisfactorily, owners of shipping and sea travellers during the period of the World War have reason to know. Later achievements are of a more pacific character. The gyro ship stabilizer, the gyro-compass, in view of its superior performance, and other instruments to aid navigation are rapidly gaining favor despite the considerable additional cost entailed by this kind of equipment.

The practical method of approach in the solution of gyro problems has been by no means neglected in works of recent times, but with the advantages of accumulated precedent, the author has gone an important step further toward bringing the subject within the realm of commercial design. He employs the

direct methods of the simple dynamical equations to which the ordinary graduate in engineering is accustomed and continues to use in his professional calling. As Professor Ferry expresses it: "The purpose of the present book is to bring gyrodynamics out from behind the integral signs. . . ." Proceeding according to this plan, with the aid of a generous number of illuminating diagrams, he analyzes very fully the dynamics of the gyroscope. Interspersed in the analysis are references to numerous gyro apparatus now in use. That feature of keeping constantly in view the physical aspects of the phenomena under examination is of obvious value in lessening the labor of mastering the subject. Most of this analytical discussion occupies the first half of the book.

In the second half of the work, the discussion is applied to a surprisingly large number of gyroscopic control devices which have been in successful use. Among these may be mentioned the gyro-horizons, gyro-sextants, the air-plane pilot, the track recorder and gun-fire control apparatus. Among the major topics are the anti-roll devices for ships, and gyro-compasses, the last mentioned being treated very fully. Finally, in a chapter on the principles of static and kinetic stability, the properties and limitations of several types of monorail cars are examined at considerable length.

The author has obviously been unsparing of a well-directed effort in gathering together a comprehensive collection of representative gyro apparatus which is probably unequalled in text-book form in point of teaching value to the reader who seeks a sound and applicable knowledge of the subject.

L. E. P.

PUBLICATIONS RECEIVED.

Physikalisches Handworterbuch, herausgegeben von Arnold Berliner und Karl Scheel, Zweite Auflage, 1428 pages, diagrams, quarto. Berlin, Julius Springer, 1932. Price 96 marks, in paper.

The Kinetics of Homogeneous Gas Reactions, by Louis S. Kassel, American Chemical Society Monograph Series, 330 pages, tables, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1932. Price $6.50.

Recent Advances in Physics (Non-Atomic), by F. H. Newman, 378 pages, illustrations, tables, 8vo. Philadelphia, P. Blakiston's Son & Co., Inc., 1932. Price $4.00.

English-German and German-English Dictionary of Chemistry, by Willy H. Thurow, Part II, German-English, 287 pages, 16mo. Berlin, Dr. Arthur Tetzlaff, 1932.

A Treatise on Photo-Elasticity, by E. G. Coker and L. N. G. Filon, 720 pages, illustrations, tables, plates, quarto. Cambridge, University Press, 1931. Price $17.50.

Les Principes Physiques de la Theorie des Quanta, par W. Heisenberg, Traduit de l'Allemand, par MM. B. Champion et H. Hochard, Preface de M. Louis de Broglie, 126 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1932. Price 40 fr.

L'Hydrodynamique et la Theorie Cinetique des Gaz, par Y. Rocard, Preface de Henri Villat, 160 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1932. Price 40 fr.

U. S. Coast and Geodetic Survey: Results of Observations made at The United States Coast and Geodetic Survey Magnetic Observatory near Honolulu, Hawaii in 1925 and 1926, 107 pages, plates, tables, quarto. Washington, Government Printing Office, 1931. Price 45 cents. Results of Observations made at The United States Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland, in 1925 and 1926, 100 pages, tables, plates, quarto. Washington, Government Printing Office, 1931. Price 45 cents.

Conferences d'Actualites Scientifiques et Industrielles. 19, La Haute Precision des Mesures de Longueur, par M. A. Perard. 20, L'Effet Photo-Electrique des Rayons X dans les Gaz, par Pierre Auger. 22, Fluorescence Duree Elementaire d'Emission Lumineuse, par Francis Perrin. 23, Les Recents Progres de la Desintegration Artificielle des Elements, par Maurice de Broglie. 25, Les Applications des Rayons X a l'Etude des Composes Organiques, par M. J. J. Trillat. 26, L'Etat Liquide et les Etats Mesomorphes, par M. J. J. Trillat. 27, Les Systemes Autoentretenus et les Oscillations de Relaxation, par Ph. Le Corbeiller. 28, Le Quartz Piezo-Electrique ses Applications a la T. S. F., par F. Bedeau. 29, L'Hydrogene est un Melange: Ortho et Parahydrogene, par Eugene Darmois. 30, Les Piles Sensibles a l'Action de la Lumiere, par M. Rene Audubert. 10 pamphlets, illustrations, 8vo. Paris, Librairie Scientifique Hermann et Cie, 1931. Price five to eight francs.

Monaco, International Hydrographic Bureau, Year Book, 1932, 158 pages, 12mo.

National Advisory Committee for Aeronautics, Technical Notes, No. 404, Tests of N. A. C. A. Airfoils in the Variable-Density Wind Tunnel, Series 24, by Eastman N. Jacobs and Kenneth E. Ward, Langley Memorial Aeronautical Laboratory, 19 pages, tables, diagrams, quarto. Washington, Committee, 1932. No. 405, Valve Timing of Engines having Intake Pressures Higher than Exhaust, by Edward S. Taylor, Massachusetts Institute of Technology, 7 pages, plates, quarto. Washington, Committee 1932. No. 407, Effect of the Reservoir Volume on the Discharge Pressures in the Injection System of the N. A. C. A. Spray Photography Equipment, by A. M. Rothrock and D. W. Lee, Langley Memorial Aeronautical Laboratory, 9 pages, plates, quarto. Washington, Committee, 1932.

CURRENT TOPICS.

Longest Bridge in the Balkans is Completed. (*Engineering News Record*, January 14, 1932.) The bridge across the Danube joining Belgrade directly with the Banat, at Panchevo, has recently been completed. This bridge, 1,379 yds. long and 36 ft. wide, is the longest in the Balkan Peninsula and one of the longest in Europe. About 20,000 tons of steel and 100,000 cu. m. of concrete were required in the structure. The bridge serves for both railway and road transport and has been constructed so that if need arises it can be widened to 66 ft.

R.

Longest Concrete Arch Span. (*Popular Mechanics*, February, 1932.) Two hundred and sixteen feet above the stream, the new George Westinghouse bridge soon will replace the old Indian trail to the west, spanning the wide Turtle Creek valley near Pittsburgh. It is the critical link in the new Lincoln highway cut-off, shortening time and distance between Pittsburgh and the east. The improvement, almost five and a half miles long, eliminates a hill with a nine-per-cent. grade, dangerous curves and long the cause of much traffic congestion. The bridge consists of five reinforced-concrete arches, of which the central one is 460 feet long and said to be the largest concrete-arch span yet built in the United States. When finished, the total cost of the bridge will be about $4,500,000.

R.

Photochemical Polymerization of Acetylene. S. C. LIND AND ROBERT LIVINGSTON (*Jour. Am. Chem. Soc.*, 1932, **54**, 94–106) have obtained a yellowish solid resembling cuprene by the polymerization of acetylene as the result of irradiation by ultra-violet light in the absence of mercury vapor. The rate of polymerization apparently is governed by the intensity of the absorbed light; the wave-length must be less than 2537 Angstrom units.

J. S. H.

Liquid Hydrogen Fluoride. J. H. SIMONS AND J. W. BOUKNIGHT (*Jour. Am. Chem. Soc.*, 1932, **54**, 129–135) have determined the density of liquid hydrogen fluoride within the temperature range $-75°$ to $+5°$ C. They find that the density, d, at any

given temperature, t, is expressed by the equation

$$d = 1.0020 - 0.0022625t + 0.000003125t^2.$$

They have also determined its surface tension in the temperature range $-80°$ to $+19°$ C., and found its value to be expressed by the formula $\gamma = 40.7\left[1 - \frac{T}{503.2}\right]^{1.78}$. Apparently the liquid is a polymer. J. S. H.

How Hot or Cold Is It?—To avoid arguments as to how hot or cold it is the U. S. Department of Agriculture advises us to hang the thermometer on the north side of the house in a sheltered place, such as a porch, and be sure it is an inch or two away from the wall. Of course such precautions are worthless if the thermometer has not been accurately made or calibrated. (U. S. Dept. of Agriculture, Clip Sheet No. 709.)

T. K. C.

Freezing Trees in Study of Disease.—The U. S. Department of Agriculture reports that apple-disease specialists of the department studying the connection between low temperatures and perennial canker have frozen limbs of trees to very low temperatures, using a device especially made for that purpose.

The freezing apparatus consisted of an insulated box which was fitted around a limb. Freezing was brought about by using snow and salt in a mixture in the box and also by using solid carbon dioxide. Temperatures as low as 40° below zero were reached. (U. S. Dept. of Agriculture, Clip Sheet No. 708.)

T. K. C.

Black Locust Has Many Uses.—Black locust is a 4-purpose tree, says the U. S. Forest Service. It quickly produces good timber for posts and other uses; it roots strongly, thereby checking soil erosion; its flowers enable bees to make a good quality of honey; and it is a legume. That is, the nodules on its roots store nitrogen in the soil, enriching it for future crops. In addition, it is a tree of beauty and is valuable for shade. (U. S. Dept. of Agriculture, Clip Sheet No. 708.)

T. K. C.

Progress in Aviation and Aeronautics.—JOSEPH S. AMES in a summary of the Seventeenth Annual Report of the National Advisory Committee for Aeronautics, 1931, states that the demand

for aircraft to be used in commercial air transportation may be expected to increase slightly, but not to an extent sufficient to maintain an adequate aircraft manufacturing industry. There has been a reduction in the manufacture of airplanes for private use, the chief reason for which is probably the fact that the airplane for private use has not been developed to that degree of safety, performance, and economy necessary to bring about its extended use by private owners.

The Committee strongly recommends continued work upon the fundamental problems confronting aviation in all its branches. In military, commercial, and private aviation there must be improvement in the performance and in the efficiency of aircraft, and in private aviation especially there must be greater safety and greater economy in production, maintenance, and operation costs. The major problems are to increase the aerodynamic efficiency of aircraft, the operating efficiency of engines, and the control of airplanes at low speeds. Next in importance come the problems of simplifying design and of making possible lower costs of construction, maintenance and operation.

T. K. C.

Recent Developments in the Autogiro.—A letter issued by the Autogiro Company of America announces the construction of an autogiro of a revolutionary " pusher " type. As the name implies, the propeller and motor are situated in the rear and propulsion is accomplished by the pushing action of the propeller rather than by pulling which is the almost universal method. This new pusher-type has many attractive features such as improved visibility, absence of fumes, noise and dirt. The gross weight of this machine is 2,000 pounds and its weight empty 1,400. It is especially designed for aerial photography, mapping, and the business man or sportsman-pilot. The engine has 165 horsepower.

T. K. C.

Toxic Fogs.—Many can still recall reading in the newspapers of Dec. 5 and 6, 1930, an account of the sudden appearance of a toxic fog in a more or less confined locality in Belgium. This fog proved fatal to cattle and a considerable number of human beings, particularly those of advanced age or suffering from some pulmonary affliction. Much speculation and controversy as to the cause of these fogs arose at that time and have recurred intermittently ever since.

In the *Ind. & Eng. Chem.*, News Edition, Jan. 10, 1932, C. Mathy submits an account of the report issued by the Official

Investigation Commission assigned to find the cause of this catastrophe. The Commission places the responsibility upon sulfuric acid which is produced—by oxidation with the oxygen of the air in contact with the droplets of water in the fog and dust suspended therein—from the sulfur dioxide which all the industrial and domestic hearths of the Meuse Valley between Liege and Engis send forth into the atmosphere. In order for this oxidation to have occurred in the known proportions, particular atmospheric conditions were necessary, transforming the valley into a sort of closed vessel in which it has been ascertained that the pollution from countless local factories and dwelling houses has accumulated on the banks of the Meuse. These conditions are frost, wind of very slight force and intense fog.—Not everyone is satisfied with this explanation and quite possibly the last word has not yet been said.

T. K. C.

Transparent Nickel.—The *White Metal News Letter* (the International Nickel Co.) tells of nickel in such thin sheets that it is possible to read print through five thicknesses of the metal placed a few millimeters apart. The thin sheets were made by electrodepositing nickel upon copper and then plating copper upon the nickel—a nickel sandwich. The copper was then dissolved away, leaving the nickel. Copper was required on both sides to equalize the stresses caused during the dissolving of the copper, which might have ruptured the nickel film.

T. K. C.

Palladium Leaf.—(*White Metal News Letter.*) After two years of experimentation Theodore Koch and Dr. J. S. Streicher of the American Platinum Works have perfected a precious metal white leaf which will take its place with gold leaf. This leaf is produced by beating palladium, a metallic element closely related to platinum. Palladium was discovered in 1803 and was named in honor of the then recent discovery of the planetoid, Pallas.

Prior to the development of palladium leaf the decorative art has not enjoyed having a truly non-tarnishing white leaf possessing the same resistance to oxidation as gold leaf. In the tarnish tests, the thin palladium leaf was subject to a temperature of 150° F. for a period of eight days in an atmosphere which contained traces of sulfur. According to Koch, the bright surface of the leaf was unaffected. Not until the temperature exceeds 572° F. does palladium become subject to oxidation.

Palladium has the soft whiteness of color and depth of tone of platinum. As a pleasing substitute or contrast for gold leaf palla-

dium leaf should find a wide variety of applications. It should prove particularly attractive to the bookbinder for stamping titles and designs on leather as well as other uses requiring a white precious metal not affected by the tannic acid with which leather is tanned.—Thirty-five square feet of palladium leaf, which constitutes a book of 500 sheets of leaf, weighs less than one-quarter of an ounce.

T. K. C.

Soil Erosion.—H. H. BENNETT, soil scientist of the U. S. Department of Agriculture, states that " The erosion of soil in the United States is far more widespread than has been supposed, even by soil workers, and it has destructive possibilities almost beyond human comprehension. To erosion is ascribed the credit for having modified the surface of the earth more than the combined activities of volcanoes, earthquakes, tidal waves, tornadoes and all the excavations of mankind since the beginning of history."

" It takes nature at least 400 years to build one single inch of valuable topsoil such as is found in portions of the Corn Belt. The Shelby loam of Missouri and Iowa is a good example. In northern Missouri, it takes just seven years under continuous corn growing for one inch of this Shelby loam to wash off land having a slope of about four feet in a hundred and only one year to remove the same depth from land sloping eight feet in a hundred, this by actual measurement. The plant food removed from the fields and pastures of America every year by erosion is at least 21 times more than that removed by the crops harvested."

T. K. C.

Fifteen Million Pounds of Butyl Alcohol.—Butyl alcohol is the fourth member in the series of alcohols of the simplest type known to chemists. The three preceding members taken in order are methyl, ethyl and propyl alcohol. Methyl is more popularly known as " wood " alcohol the greatest source of which used to be the wood distillation industry. Now it is necessary only to pass especially prepared water gas (hydrogen and carbon monoxide) over a zinc oxide or other suitable catalyst. Ethyl alcohol, commonly termed " grain," needs no introduction. For its production, merely place the raw materials in a suitable environment and let nature take its course. The member immediately following butyl is called amyl alcohol which is more familiarly known as " fusel oil."

But to return to the title subject. An outstanding chemical company has recently erected a new plant capable of producing

15,000,000 pounds of butyl alcohol annually. Two-thirds of this quantity already has been sold under contract and probably the lacquer industry now has a plentiful supply of a new raw material. Details of manufacture are not yet available.

T. K. C.

Taking Pictures with Invisible Light.—Not so long ago a group of visiting scientists sat in total darkness in the projection room of the new research laboratory of the Eastman Kodak Company. While this darkness prevailed a picture was taken of the group. The eye of the camera had gone the human eye one better, thanks to knowledge made available through research. Infra-red rays, invisible to the human eye, made possible the taking of this picture. The source of radiation was a battery of fifteen 1-kilowatt lamps in a booth covered with a special type of light filter which transmits no visible light but allows to pass very freely the infra-red rays in the region between 800 and 900 mu. The photographic plate used had a high sensitivity to light of this range and also was hypersensitized with ammonia. The exposure was one second at f/2.5.

T. K. C.

3000° C.—In the *Research Laboratory Record*, Vol. 1, No. 2, FRANK T. CHESTNUT describes a series of tests made to determine just how high a temperature could be feasibly reached and maintained on a commercial scale. The furnace was of the inductor type which means the heating is done by surrounding the substance with a metal conductor through which a high-frequency current is passing. This conductor generally takes the form of a hollow tubular coil cooled by the flowing of water through its hollow interior. A piece of metal or conducting material in which induced currents may be caused by a rapidly changing electric field can be melted in short order if surrounded by this high-frequency conductor.

In these particular tests the source of heat was an Acheson graphite energy absorbing crucible. This crucible was thoroughly insulated from the conductor surrounding it by means of a special form of lamp black which gives off little or no gas at the highest temperature. It is startling to realize that such a steep heat gradient may exist in a setup of this kind. While graphite was being vaporized at 3600° C. on the inside of the crucible, the outside of the furnace only three inches away remained cold.

Temperatures high enough to vaporize graphite were secured. This vapor could be condensed to yield a rosette of extremely beautiful and soft amorphous graphite. The deposit seemed to

grow and take on the form of a heavy fern leaf or of a pine bough weighted down with snow (not done in true colors of course). Ordinary rocks of silica or magnesia base were quickly disintegrated into the vapors of their elements. These vapors were forcibly expelled from the furnace to reburn in the air with the vivid white flames of magnesium or metallic silicon. Small pieces of wood were converted to gas almost instantly. A piece, a one-quarter inch cube, was almost enough to blow the furnace apart. Fragments appeared to have been burned to carbon then transformed to graphite.

Iron which vaporizes at 2400° C. seemed to form a carbide very quickly and remain as such almost up to the vaporization temperature of graphite. At this point a very vigorous reaction occurred and a blue and white flame roared out into the air. In one case where the power was kept on too long these gases wrecked the furnace.

These tests marked a decided advance in the art of producing high temperatures and keeping them under control. The investigators speculate as to what might be accomplished if the whole furnace were enclosed in a high pressure cylinder. So long as the graphite cannot escape as a gas from the confines of the induction coil there is no limit apparently to the temperature attainable. To reduce graphite to a liquid certainly would seem to be an extremely interesting and worthwhile accomplishment.

T. K. C.

Philadelphia to Norristown in Sixteen Minutes.—The *Electrical Engineering* for December 1931 contains a short description of the new high speed electric cars recently placed in service by the Philadelphia and Western Railway Company. The outstanding feature of these cars is their shape which conforms to many of the latest ideas on stream line construction. The designers were assisted by Prof. F. W. Pawlowski, professor of aerodynamics at the University of Michigan, who conducted a series of exhaustive wind tunnel experiments to discover what design or form of car would cut wind resistance to a minimum. As a result, each end of the car has a sloping roof and pointed nose. The windows are flush with the side surfaces of the car and the underfloor equipment is arranged so as to reduce air resistance. The entire body is aluminum.

Wind-tunnel tests show that when a car of conventional design travels between 70 and 80 miles per hour more than 70 per cent. of the total power is consumed in overcoming air resistance. The stream-line design of these new cars will save approximately 20 per

cent. of the power required to propel them at speeds above 60 miles per hour.

The weight per horse power of the 600-volt motors has been reduced from the usual value of 30 to 35 lb. per hp. to 26.8 lb. per hp. Self-ventilation of the motors has been improved by a fan mounted on the commutator end of the shaft. An improved motor control system automatically holds the starting currents at the highest permissible values, thus giving maximum acceleration at all times. There are four 100 hp. motors in each of these 52-passenger cars and the running time of express cars from Norristown to the 69th street station will be cut from 24 to 16 minutes.

T. K. C.

Plant Growth Unchanged by Ultra-Violet Glass. (U. S. Department of Agriculture Clip Sheet No. 710.) The Department reports that experiments with tomatoes, peppers and radishes in cold frames in which several types of commercial ultra-violet ray transmitting glass were used have shown that although the special glass does not result in increased growth, it is equal to common glass for this purpose.

It is pointed out that glass used in cold frames under practical growing conditions becomes dirty easily and this interferes with the transmission of the light rays. In addition, the removal of the sash for the purposes of watering and ventilation would tend to eliminate any small differences in conditions that might possibly distinguish between the different glasses were they to be left permanently in place.

T. K. C.

A Quick Test for Air Pollution. (U. S. Department of Agriculture Clip Sheet No. 710.) The statement that millions of tons of sulphur dioxide are thrown out into the air of this country each year with smoke and fumes from factories, ore-reducing and smelting plants is probably no exaggeration. These gas particles cause the condensation of the water vapor in the atmosphere to form small droplets of dilute sulfurous acid. This acid slowly combines with the oxygen of the air to produce sulfuric acid which in the concentrated state is familiar to many as "oil of vitriol." Both these acids will have injurious effects upon plants of the field, forest and garden as well as upon the lesser animate objects such as metals, building materials and leather.

A fuller recognition of this situation has given impetus to a study of means for control and as a corollary, the development of apparatus which will permit an accurate and rapid determination of

the relatively small quantities of corrosive gas constantly present in the atmosphere of industrial localities. S. W. Griffin and Dr. W. W. Skinner of the Bureau of Chemistry and Soils have perfected a new method which consists in removing the sulfur dioxide from polluted air by passing known volumes of the air through scrubbers containing solutions that absorb the gas. The apparatus is mounted in a small portable box. The rapidity of the determinations is facilitated by having two or more absorption tubes so that while the contents of one are being analyzed the other will be in the process of securing the next sample. A single test is completed in from 2 to 6 minutes. The air suction needed for making these tests may be obtained from the manifold of an atutomobile engine or by means of a rotary blower operated either by hand or by electricity.

T. K. C.

Through-the-Looking-glass Chemistry. Many members of The Franklin Institute will recall with pleasure a demonstration of the fifth-string cello given in the hall of the Institute by the inventor, Professor V. Karapetoff of Cornell University. Not so very long ago the professor delivered a very learned and scholarly address on "The Electric Nature of Chemical Affinity." Apparently as a reaction to the seriousness and dignity of this occasion the speaker penned the following bit of whimsical generalization on the nature and affinity of two imaginary atoms, the type that delighted the now outmoded alchemist. It reads:

Dear—

Supplementing my talk, please give the boys at the Night Nursery the following generalized information. If we have two chemical elements, say Doggium and Cattium, of which the atom of doggium has a single electron in a highly elliptic external orbit, whereas in the cattium an electron is missing in the outer nearly spherical shell, then doggium cattide will exist as a stable salt.

You can think of the external or valence electron as a canine tooth which the atoms of doggium and cattium share in common. If two canine teeth are shared, the formula becomes Dg_2Ct.

One can also predict that one or more stable doggium oxides exist, whereas cattium will readily combine with hydrogen forming hydrocattic acid. . . .

Sincerely,
Kary.

Apparatus for Continuously Recording the Height of the Kennelly-Heaviside Layer. (*Bureau of Standards Journal of Research*, Vol. 7, No. 5.) The Kennelly-Heaviside Layer, supposedly a

stratum of ionized gases which possesses a characteristic impenetrability to radio waves and causes them to be reflected back toward the earth. To the presence of this layer are attributed numerous irregularities in radio transmission and reception. The fact that often a short-wave station cannot be heard within a radius of one hundred miles or more is attributed to the fact that the waves are not travelling along the surface of the earth but are directed outward until they are reflected back from the Kennely-Heaviside layer many miles beyond their point of inception. This multiple reflection is responsible for the so-called echoes in long distance reception and the double or multiple image often experienced in television.

Obviously, such facts as the height of these reflecting layers of gases command considerable interest and any apparatus making possible the continuous automatic recording of these elevations will be looked upon as an enormous labor saver. In this particular apparatus, pulses are sent out from a transmitter which is keyed by a chopper driven by a synchronous motor. The pulses are of short duration, about 2×10^{-4} seconds. At the receiving station the pulses are recorded by means of an oscillograph element the light from which is reflected on to a photographic film by means of a mirror rotating in synchronism with the chopper at the transmitting end. The recording system is so arranged as to give a series of lines running the length of the film. The first line represents the pulse transmitted by the wave passing along the surface of the earth and which reaches the receiving instrument ahead of those travelling by the longer routes of deflection from the Kennelly-Heaviside layers. The ground-wave line remains in a fixed position upon the film but the distances between it and the other lines vary as the height of the layers changes. T. R. Gilliland and G. W. Kenrick claim the following advantages for this apparatus. It gives a continuous automatic record, requires only a fraction of the amount of film used by other methods, requires little attention, will record heights of two or more layers simultaneously and is relatively free from power line and atmospheric disturbances.

T. K. C.

Colloid Chemistry and Insanity. Functional mental disorders have in the past resisted very successfully attempts to correlate them with pathological conditions demonstrable by either abnormal anatomical or physiological states. Although many refinements in physical and chemical methods are now available it would seem they hardly have been brought to that degree of *n*thness which will

detect that particular abnormal condition responsible for these disorders.

The assumption that functional phychoses are attributable to peculiar states of dispersion of the colloids existing in brain and nerve cells has received noteworthy support through the investigations of H. B. Long, John A. Patterson and Wilder D. Bancroft. Their findings and views will be found in the *Journal of Physical Chemistry* for December, 1931. Their methods consisted in giving mentally deranged patients doses of sodium amytal and of sodium rhodanate (sodium thiocyanate). Sodium amytal exerts a coagulating effect upon colloids while the action of sodium rhodanate is just the reverse and brings about what is known as peptization or dispersion. Forty-six cases were studied under both drugs. In thirty-eight of these cases, positive results were obtained: If the patients reacted favorably toward sodium amytal then they became worse when given sodium rhodanate and vice versa. From these results the authors draw the conclusion that at least two abnormal conditions of the brain can exist, one when it is over-coagulated, the other when over-peptized and that there exist certain types of insanity which respond to a treatment by chemicals which tend to restore the brain colloids to a normal state of dispersion.

T. K. C.

Cherry Gum. C. L. BUTLER AND LEONARD H. CRETCHER (*Journal of the American Pharmaceutical Association*, 1932, *21*, 24–30) have hydrolyzed cherry gum and found it to yield uronic acids. From the aldobionic acid fraction were obtained galactose and methylated uronic acids. Methoxyl groups were not detected.

J. S. H.

Spinasterol. MERRILL C. HART AND FREDERICK W. HEYL (*Journal of Biological Chemistry*, 1932, *95*, 311–315) have isolated from spinach a new sterol, spinasterol, which melts at 168 to 169° C., and has a specific rotatory power of — 1.8° at 25° C. in sodium light. They have prepared its esters with acetic, propionic, butyric, trichloroacetic, benzoic and para nitrobenzoic acids, and phenyl urethane. It reacts with chloroacetyl chloride to yield the derivative of a metameric compound, isospinasterol chloroacetate.

J. S. H.

The Bermuda Railway (*Railway Mechanical Engineer*, February 1932). Faced with the problem of providing some means of mechanical transport for a resident population of 32,000 plus large numbers of tourists, but unwilling to lift the legal ban in existence

since 1908 on automotive highway vehicles, the government of the British crown colony of Bermuda authorized, a few years ago, the construction of a railway. Although original plans contemplated completion of the project during the spring of 1928 at a cost of about $2,000,000, Bermuda Traction, Ltd. (now the Bermuda Railways Investment Co., Ltd.), organized under the terms of the Bermuda Railway Act to build the new line, found considerable difficulty in obtaining necessary land at reasonable prices, with the result that actual construction was long delayed and total cost materially increased. These difficulties being finally overcome with government assistance, the western section of the line, from Hamilton to Somerset, was formally opened to traffic on October 31, 1931, at which time the eastern branch was also near completion.

The new 22-mile railway serves the entire length of the main islands, from Hamilton, the centrally-located capital, west to the British naval base at Somerset, 11 miles, and east to St. George, also 11 miles. The single tract is of standard 4-ft. 8½-in. gage, and is laid with 67½-lb. rail on timber crossties.

All traffic is to be handled by rail motor cars; six for passengers and two for freight, together with an equal number of trailers for each class of service. Each passenger motor car, weighing 20 tons, accommodates 16 first- and 26 second-class passengers on reversible upholstered or wooden seats, while the trailers, all first-class, weigh 14 tons and seat 40 passengers in individual arm chairs. The cars are mounted on steel under-frames carried on four-wheel trucks, those bearing the power units being interchangeable so that during overhauls a spare stand-by unit may be substituted, making it unnecessary to withdraw the coach from service. Parsons 6-cylinder 4¾-in. by 6-in. engines, with a continuous rating of 120 hp. at 1,650 r.p.m., supply the motive power, which is applied to the trucks by a straight-line transmission; while the Wilson-Drewry epicyclic preselective gear box, giving five speeds both forward and reverse, is used for the first time in railway service. This gear, which has shown about 99 per cent. test efficiency, makes it possible to reduce the pneumatically-operated control to its simplest form and to provide automatic engagement of gears at a constant rate under all conditions. Electric lighting, electric self-starters and air and hand brakes are also standard.

Shops equipped to make either running repairs or complete overhauls of all rolling stock are located at Hamilton.

R.

Gasoline-Propelled Railway Cars, equipped with rubber tires, have been constructed in France. These cars are intended for

high-speed service, and are said to have given excellent results in recent tests. They are built extremely light and designed with a view to reducing wind resistance. The effects of the rail joints on vibration are said to be practically eliminated, and the cars run very smoothly. (*Machinery*, February 1932.)

R.

Secret Television. (*Popular Science Monthly*, March 1932.) Secret transmission of television images is proposed through a method with which an Eastern firm is experimenting. The image would be distorted optically by lenses at the transmitting end, so that ordinary television receivers in general use would get only a blurred and meaningless picture. But a receiver equipped with the proper lenses of secret curvature would be able to restore the image to its proper shape. In this way, it has been suggested, international conferences might be held privately without the need of any participant leaving his country, and business contracts could be executed with the parties meeting face to face by television. Methods have already been perfected whereby conversation may be "scrambled" for secret transmission. A system of electrical scrambling is now in use in transmitting point to point telephone conversations across the Atlantic ocean.

R.

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The Certificate of Merit.—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

The Boyden Premium.—Uriah A. Boyden, Esq., of Boston, Mass., has deposited with The Franklin Institute the sum of one thousand dollars, to be awarded as premium to "any resident of North America who shall determine by experiment whether all rays of light and other physical rays are or are not transmitted with the same velocity."

For further information relating to these awards apply to the Secretary of the Institute.